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DATA ACQUISITION SYSTEMS IN WATER QUALITY MANAGEMENT

Robert C. Ward

Colorado State University

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Data Acquisition Systems in Water Quality Management

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27 Abstract

The role of routine water quality surveillance was investigated, including a delineation of the objectives a state water quality program based upon the state and federal laws. Seven specific objectives are listed under the two general objectives of prevention and abatement: planning, research, aid programs, technical assistance, regulation, enforcement, and data collection, processing, and dissemination. Each objective was broken down into the general activities required for its accomplishment and the data needed for each activity ~~was~~ identified.

A survey of systems for grab sampling, automatic monitoring, and remote sensing was performed, each data acquisition technique being analyzed for capabilities, reliability, and cost.

A procedure was developed for designing a state water quality surveillance program responsive to objectives. The design procedure has two major aspects: (1) determination of the agency's control strategy, and (2) characterization of streams according to use and quality conditions. The optimum grab sampling network is then designed and possibilities of substititing automatic monitoring and remote sensing at various points in the network are explored.

The design procedure was applied to the State of Colorado and a water quality monitoring system was developed for the Water Pollution Control Division of the Colorado Department of Health. Financial and manpower constraints were considered in the design. (EPA)

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DATA ACQUISITION SYSTEMS IN WATER QUALITY MANAGEMENT

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ABSTRACT

The role of routine water quality surveillance in a water quality management program was investigated. This included a delineation of the objectives a state water quality program based upon the state and federal laws. Seven specific objectives are listed under the two general objectives of prevention and abatement. These seven specific objectives are planning, research, aid programs, technical assistance, regulation, enforcement, and data collection, processing, and dissemination.

The information requirements of the objectives were delineated in general terms. Each objective was broken down into the genreal activities required for its accomplishment and the data needed for each activity was identified.

A survey of the current state-of-the-art of grab sampling, automatic monitoring, and remote sensing was performed. Each data acquisition technique was analyzed as to its capabilities, reliability, and cost.

With the above information, a design procedure was developed for designing a state water quality surveillance program which is responsive to the objectives of the agency. The design procedure has two major aspects: (1) determination of the state agency's strategy with respect to its attack on water pollution, and (2) characterization of the streams in the state so that rational decisions with respect to sampling location and frequency can be made. The optimum grab sampling network was designed and then the possibilities of substituting automatic monitoring and remote sensing and various points in the surveillance system were explored.

The design procedure was applied to the State of Colorado and a water quality monitoring system was developed for the Water Pollution Control Division of the Colorado Department of Health. Financial and manpower constraints were considered in the design.

This report was submitted in fulfillment of Project Number 1609 FUO, under the (partial) sponsorship of the Environmental Protection Agency.

CONTENTS

Section		Page
I	Conclusions	1
II	Recommendations	3
III	Introduction	5
IV	General Objectives of State Water Quality Control Programs	7
V	Data Requirements of General Objectives	19
VI	State-of-the-Art Summaries	31
VII	Design Procedure for Water Quality Surveillance Systems	39
VIII	Application of Design Procedure to Colorado	61
IX	Acknowledgments	125
X	Literature Cited	127
XI	Appendices	129

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FIGURES

		Page
1	BREAKDOWN OF THE OBJECTIVES OF A STATE WATER QUALITY MANAGEMENT PROGRAM	10
2	SUMMARY OF DATA NEEDS AS RELATED TO THE WORK ELEMENTS	28
3	STRATEGY EVALUATION FOR STATE WATER QUALITY MANAGEMENT PROGRAMS	41
4	POLLUTION CONTROL STRATEGY ASSOCIATED WITH DATA ACQUISITION STRATEGY	45
5	FLOW DIAGRAM FOR SURVEILLANCE NETWORK SIMULATION	50
6	EXAMPLE INSTANTANEOUS SPILL DISPERSION CURVE	53
7	POLLUTION CONTROL STRATEGY DETERMINATION FOR COLORADO AS COMPLETED BY A WPCD STAFF MEMBER	66
8	CACHE LA POUDRE RIVER - SEPTEMBER 1970	73
9	DETECTION VERSUS NUMBER OF SAMPLES FOR ONE STATION AT LOWER END OF REACH WITH 0-3 DAY RANDOM SPILL DURATION	81
10	DETECTION VERSUS NUMBER OF SAMPLES PER STATION FOR CONSTANT NUMBER OF TOTAL SAMPLES FOR 100 MILE REACH	83
11	SPILL DETECTION BY ONE STATION AT END OF 20 MILE REACH FOR ONE, TWO AND FOUR SAMPLES DURING ONE MONTH PERIOD	85
12	SPILL DETECTION BY ONE STATION AT END OF 20 MILE REACH FOR EIGHT AND TWELVE SAMPLES DURING ONE MONTH PERIOD	86
13	SPILL DETECTION BY ONE STATION AT END OF 20 MILE REACH FOR SMALL SPILL DURATION AND VARIOUS NUMBERS OF SAMPLES DURING ONE MONTH PERIOD	87
14	DETECTION OF INSTANTANEOUS SPILLS	88

FIGURES

Page

15 DETECTION VERSUS SAMPLING FREQUENCY FOR VARIOUS SPILL DURATION RANGES 90

16 DETECTION EFFECTIVENESS VERSUS NUMBER OF SAMPLING STATIONS PER STREAM WITH A CONSTANT SAMPLING FREQUENCY OF 12 SAMPLES PER YEAR PER STREAM 91

17 NUMBER OF SAMPLES VERSUS ALLOWABLE ERROR FOR σ EQUAL ONE AND TWO 95

18 NUMBER OF SAMPLES VERSUS ALLOWABLE ERROR FOR σ EQUAL THREE, FIVE, AND TEN 97

19 NUMBER OF SAMPLES VERSUS ALLOWABLE ERROR FOR σ EQUAL 25 AND 50 98

20 NUMBER OF SAMPLES VERSUS ALLOWABLE ERROR FOR σ EQUAL 100 AND 500 99

21 OBSERVED DEVIATION FROM TRUE MEAN 103

22 RELATIONSHIP OF COST TO NUMBER OF SAMPLES FOR COLORADO 108

23 COST-EFFECTIVENESS RESULTS FOR THE PRIMARY NETWORK IN COLORADO FOR A 0-3 DAY SPILL LENGTH 111

24 ACCURACY LIMIT VERSUS COST FOR THE SECONDARY NETWORK IN COLORADO 114

25 SECONDARY PARAMETER LIST FOR COLORADO AS REPORTED FROM STORET 117

TABLES

No.		Page
1	Application of Automatic Monitors	34
2	Effect of Number of Samples on Detection	80
3	Effect of Sampling Frequency and Number of Stations on Event Detection with Constant Number of Samples	82
4	Primary Network Analysis Results for Colorado	93
5	Sampling Frequency Compared to Effectiveness Levels for Colorado's Primary Network	94
6	Base Level Surveillance Model Results	102
7	Number of Samples Required for Various Accuracy Limits for Colorado's Secondary Network	105
8	Effectiveness Versus Cost for the Primary Surveillance Network in Colorado	110
9	Effectiveness Versus Cost for the Secondary Surveillance Network in Colorado	113

SECTION I

CONCLUSIONS

A rational and practical routine water quality surveillance design analysis can be performed using the procedures outlined in the report. The amount of refinement used in the design analysis is dependent upon the information available on the character of the streams involved. The systems analysis approach used in developing the design procedures provides an excellent basis for the development of useful and practical surveillance system design information. This information is extremely valuable to the water qualtiy manager who must make surveillance system design decisions. The systems approach used in the report also permitted the viewing of the surveillance system as a whole rather than as a series of parts. Perhaps the most important aspect of the systematic approach used in the report is the simple fact that in order to analyze a surveillance system in a broad context, it must be completely understood. This, by itself, often leads to improvements in the surveillance system.

The design or evaluation of a routine water quality surveillance network must be related to the goals and objectives of the agency collecting and acting upon the data. This helps to insure that the surveillance effort is directly supporting the agency's water quality control efforts. Depending upon the goals of an agency, some of the six general objectives discussed in this report may be emphasized over others. This, in addition to the methods of water quality control (permits, site approvals, etc.), forms the agency's strategy with respect to control of water quality. The goals, and consequently the strategy, are established by the personnel, funding levels, priorities, laws, etc., under which the agency must operate. The strategy, therefore, however relative, must be determined so that surveillance system design is relevant.

The use of automatic monitoring for routine surveillance purposes is economically competitive with grab sampling in the area of spill detection. Due to its limited parameter measurability, a parameter evaluation of the stream involved will provide the final answer as to whether automatic monitoring is practical for that stream.

Remote sensing is presently of questionable value in a routine water quality surveillance system. It is extremely useful, however, in the special surveys that should precede the development of a routine surveillance system containing grab sampling and automatic monitoring. Further development and refinement in remote sensing procedures will continue to make it a surveillance technique to be considered in both special surveys and routine monitoring.

Grab sampling will continue to be the backbone of most routine water quality surveillance systems. This is due to parameter measurability and cost. Grab sampling, however, can and should be made more effective through a thorough analysis of sampling station locations, sampling frequencies, and parameters measured. This can be accomplished through procedures given in the report.

SECTION II

RECOMMENDATIONS

1. Due to the unique self-evaluation required in the surveillance design procedure, it is recommended that each state agency be encouraged to analyze its data acquisition system using the results of this report as a guide.

2. In order to facilitate the first recommendation, it is suggested that a conference or short course be scheduled. The report could be sent to the state agencies for their review and then a representative of the agency would attend the conference at which time the design procedure would be thoroughly reviewed. The representative would then be encouraged to return to his agency and see that his surveillance network and agency are analyzed in a comprehensive and systematic manner.

3. The subject matter of this report has been mainly concerned with the actual acquisition of data. The results of this report need to be tied in closely with a data handling system such as those currently being developed by the Pennsylvania Department of Environmental Resources and the Michigan Water Resouces Commission. This would provide a sound basis for action upon data rather than reaction to a crisis.

4. There are many types and sources of data utilized by a state agency other than data from its routine surveillance network. For this reason, it is recommended that further work be instituted in the area of optimum utilization and acquisition of all data from all available sources. A project of this type may illustrate the need of an agency to rely less upon data collected internally and a need to rely more upon data collected externally. This would free agency personnel from the collection of data for the sake of data collection and would put more emphasis upon the action which is to result from analysis of data.

5. As for the application to Colorado, it is recommended that the Colorado agency use the results of the application section to evaluate their current surveillance efforts. Also, as further information becomes available the analysis should be expanded beyond that given in the report.

6. Since the efforts of any one person or group of people can in no way encompass the whole problem completely,

it is recommended that as more practical experience is gained in applying the design procedure, the procedure should be modified or refined so that it can remain a valuable tool with which to manage a surveillance system.

SECTION III

INTRODUCTION

Water quality degradation has been widely recognized as one of the urgent problems facing modern society. In response to an increasing public awareness of this problem, and in recognition of the importance of achieving and maintaining water supplies of acceptable quality, the U.S. Congress enacted a federal water quality act in 1965. The 1965 act required individual states to establish water quality standards for interstate streams and to develop detailed plans for implementing and enforcing these standards.

The Federal Water Pollution Control Act, as amended, stimulated review and revision of state statutes and institutional arrangements for the management of water quality. In many states new commissions, boards, authorities, etc., were established to handle water pollution control activities. In other states the existing agencies were given new duties and authority. These water pollution control agencies were empowered to adopt comprehensive water pollution control plans, identify sources of pollution, and to adopt and enforce water quality standards. In many states the above responsibilities presented a problem in that there was a lack of basic data on which to base an assessment of the water quality situation existing throughout the state. All states faced the problem of limited manpower when the new assignments were set forth.

In order to obtain basic data and to enforce water quality standards, the states either established or expanded their network of water quality monitoring stations. The networks command the attention of engineers, chemists, aquatic samplers, systems analysts, and other staff of the state agencies. Yet, even with the commitment of a substantial effort, it is apparent that these surveillance networks do not meet the overall needs of the water quality management programs. Many waste sources go undetected. Frequently, pollution problems have passed before their existence is noted by the surveillance system.

Thus, one must conclude that water quality sampling and data analysis consume a large portion of the valuable staff time without providing the information necessary to support water quality management programs. At the very least, one would expect that an analysis of the information obtained since the Federal Water Pollution Control Act, as amended, would indicate improvements which would make the existing systems more effective. On the other hand, it may be possible to develop an entirely different system with a much lower professional manpower requirement by turning to more advanced methods of instrumentation and data analysis. If so, the result would be to release manpower critically needed for other responsibilities.

With the above situation in mind, it will be the objective of this study to determine the role of water quality information collection and interpretation in the water quality management program and then to identify the most effective means of filling this role. In the process, the needs to be served by the water quality information collection and evaluation system will be identified, different means of obtaining and evaluating water quality information will be determined, and a water quality information system will be designed for the State of Colorado.

The different methods of information collection and interpretation to be considered will include: 1. traditional sampling techniques with laboratory analysis to identify materials in the water sample and statistical analysis of the resulting water quality data; 2. remote sensing to determine "in situ" the character of materials in the stream coupled with automated screening and analysis of data and automatic photographing of unusual events; and 3. automatic monitoring with wet-probe instrumentation coupled with automatic screening and interpretation of data, and automatic sampling and/or photography of unusual events.

Different systems will be evaluated in terms of their cost, manpower and hardware requirements, and their ability to meet the requirements of water quality management agencies. Based on this evaluation, a model water quality monitoring program will be recommended for the State of Colorado.

SECTION IV

GENERAL OBJECTIVES OF STATE WATER QUALITY CONTROL PROGRAMS

The objectives of a state water quality program must be determined from the state laws which establish the program. These laws, however, have undergone a tremendous review and revision during the past five years as a result of the Federal Water Pollution Control Act, as amended. Since this act has stimulated review and revision of state statutes, it must have had a large influence upon current state water quality control programs and, consequently, the objectives associated with the program. Because of this influence, the federal impact upon state programs will be evaluated.

Federal Influence

The Federal Water Pollution Control Act, as amended, states that its purpose is to "establish a national policy for the prevention, control, and abatement of water pollution." This seemingly broad statement is actually a very concise statement of the objectives of water pollution control. That is, the objective is simply to prevent and abate water pollution. How this objective is to be obtained is spelled out in the Federal Water Pollution Control Act, as amended. Also spelled out is the relationship between state water pollution control programs and the federal program.

The objectives stated in the federal law are to be obtained mainly through action at the state level. The federal law specifies that a state will adopt "(A) water quality criteria applicable to interstate waters or portions thereof within such State, and (B) a plan for the implementation and enforcement of the water quality criteria adopted, . . ." This then is an objective of the state water quality program--to set stream standards and enforce them. If the state does not satisfy the above federal stated duties, then the federal government will establish and enforce water quality standards in the state. This then is a directly stated legal influence upon the state program objectives.

Besides the above stated influence, the federal government offers the states money to help support the states' pollution control activities. This financial support is in the form of (1) direct program support (Section 7 Grants), and

(2) waste treatment plant construction grants. To obtain the federal money, grant applications must be completed. These applications require specific information which the state program must supply. This, therefore, is another objective of a state program; perform the necessary tasks and collect the necessary information which will insure success in obtaining federal funds.

In summary, the federal influence on state water pollution control objectives can be considered to be in two broad areas: (1) the legal requirement that each state establish and enforce water quality standards, and (2) the more indirect requirement that each state must supply the information required to obtain federal financial support for the state program. Each of these broad influences will be analyzed in more detail later in order to determine the data requirements necessary to obtain the objectives delineated through the influence.

State Legal Influence

In order to evaluate the objectives of a state water pollution control program, six sample states were chosen and their laws analyzed in detail. The objectives were determined in a general form into which all state programs could be fitted. This is not to say that each state agency will contain all the elements discussed; it is only an attempt to relate data needs to program objectives. This general form will necessarily include the general objectives imposed by the federal government since the state laws reflect the effects of the Federal Water Pollution Control Act.

Before spelling out the general objectives, it will be constructive to look at the declaration of policy and the statement of purpose which are contained in all the state laws. Each state has a declaration of policy of sorts in which it is stated that the policy of the state with regard to water pollution is to maintain the waters of the state in a reasonable state of purity which is consistent with the various uses of the water such as public health, industrial development, etc. A typical example is South Carolina's declaration,

> It is declared to be the public policy of the State to maintain reasonable standards of purity of the air and water resources of the State, consistent with the public health, safety and welfare of its citizens, maximum employment, the industrial development of the State, the propagation

> and protection of terrestrial and marine flora and fauna, and the protection of physical property and other resources.

These policy declarations indicate that water pollution control must be accomplished under the constraints that are imposed by the complex relationships of water to most activities of the state. This is saying that water is vital to many aspects of a state's activities and control of water pollution must, therefore, be considered in a systems context. These policy declarations make no statements as to the relative importance of each effect. The importance is stated later in the law and at that time the objectives related to the activities in the state can be determined.

The statement of objective or purpose of the law can be summarized in two words--abatement and prevention. This is exactly the same as the federal law statement of purpose. Abatement and prevention may not be the exact words, but these words usually summarize the intent. New York's law has a concise statement of purpose which is as follows.

> It is the purpose of this article to safeguard the waters of the state from pollution by: (a) preventing any new pollution and (b) abating pollution existing when this chapter is enacted, . . .

Objectives

By reviewing the duties of the water pollution control programs contained in the state laws, the broad objectives, prevention and abatement, can be stated in more specific terms. In general, the seven basic duties or objectives are:

1. Planning
2. Research
3. Aid Programs
4. Technical Assistance
5. Regulation
6. Legal Enforcement
7. Data Collection, Processing, and Dissemination

Planning, research, and aid programs can generally be classed as prevention, while technical assistance, regulation and legal enforcement can generally be classed as abatement. Data collection, processing, and dissemination is an objective in that it supports the first six activities. Figure 1 illustrates the type of structure envisioned by the foregoing discussion.

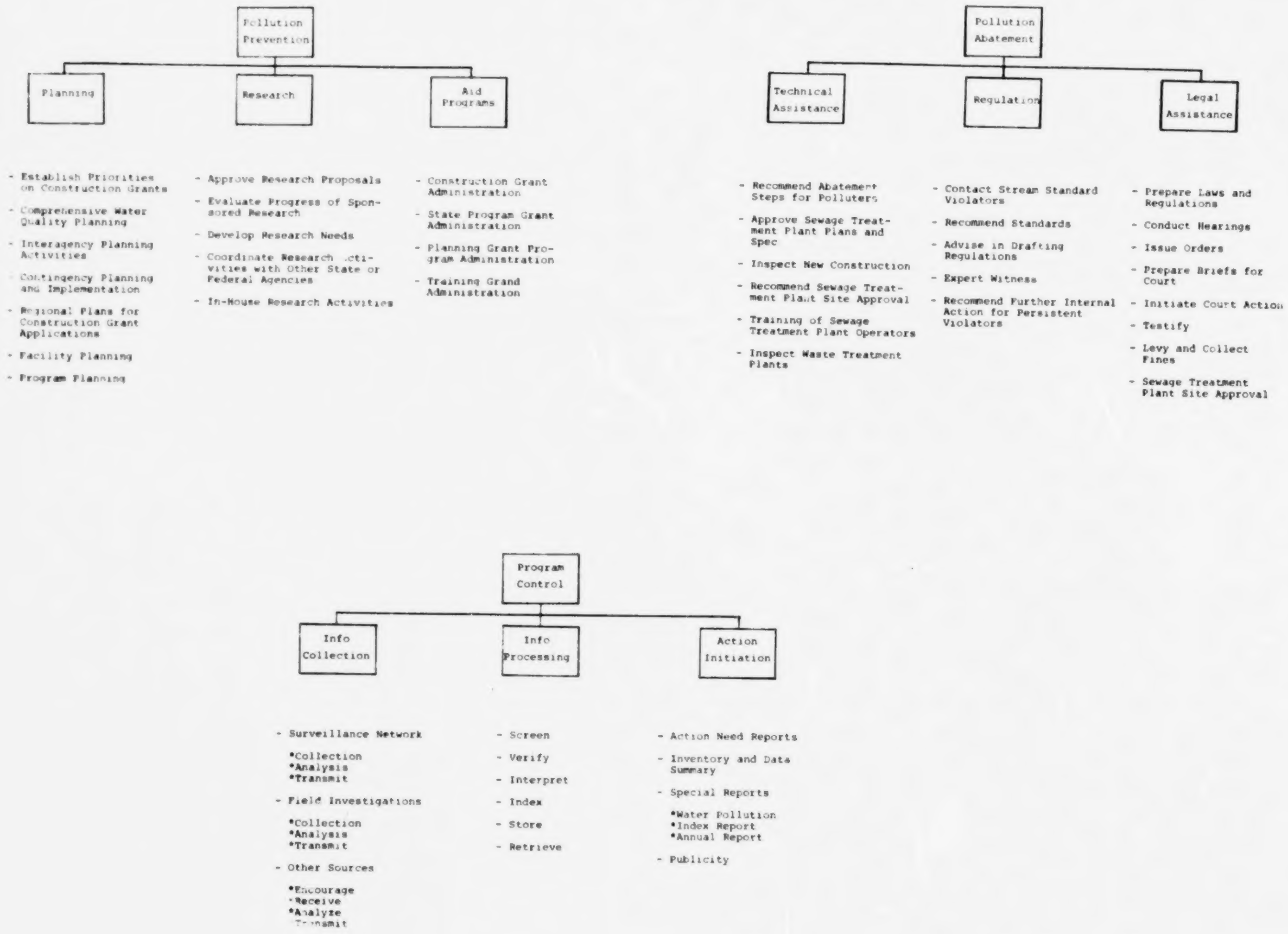
Pollution Prevention
Planning
Research
Aid Programs
- Establish Priorities on Construction Grants
- Comprehensive Water Quality Planning
- Interagency Planning Activities
- Contingency Planning and Implementation
- Regional Plans for Construction Grant Applications
- Facility Planning
- Program Planning
- Approve Research Proposals
- Evaluate Progress of Sponsored Research
- Develop Research Needs
- Coordinate Research Activities with Other State or Federal Agencies
- In-House Research Activities
- Construction Grant Administration
- State Program Grant Administration
- Planning Grant Program Administration
- Training Grand Administration
Pollution Abatement
Technical Assistance
Regulation
Legal Assistance
- Recommend Abatement Steps for Polluters
- Approve Sewage Treatment Plant Plans and Spec
- Inspect New Construction
- Recommend Sewage Treatment Plant Site Approval
- Training of Sewage Treatment Plant Operators
- Inspect Waste Treatment Plants
- Contact Stream Standard Violators
- Recommend Standards
- Advise in Drafting Regulations
- Expert Witness
- Recommend Further Internal Action for Persistent Violators
- Prepare Laws and Regulations
- Conduct Hearings
- Issue Orders
- Prepare Briefs for Court
- Initiate Court Action
- Testify
- Levy and Collect Fines
- Sewage Treatment Plant Site Approval
Program Control
Info Collection
Info Processing
Action Initiation
- Surveillance Network
•Collection
•Analysis
•Transmit
- Field Investigations
•Collection
•Analysis
•Transmit
- Other Sources
•Encourage
•Receive
•Analyze
•Transmit
- Screen
- Verify
- Interpret
- Index
- Store
- Retrieve
- Action Need Reports
- Inventory and Data Summary
- Special Reports
•Water Pollution
•Index Report
•Annual Report
- Publicity

Figure 1. Breakdown of the Objectives of a State Water Quality Management Program.

Each of the seven objectives will now be discussed as to their legal background, and a general sub-structuring of each objective will be established in order to better relate the data needs of the objective. Again, the sub-structuring is necessarily accomplished by idealizing a state's water pollution control program and is in no way an attempt to detail the activities of any one agency. Hopefully, each agency can see its various activities in the idealized structure, but at the same time some states emphasize certain areas over others. Consequently, not all states will be actively participating in all activities.

Planning

The duty of planning in a state water pollution control agency has received increased emphasis over the past few years from both the state and federal levels. The state level emphasis has been on program planning while the federal level emphasis has primarily been on project planning.

The state laws generally require the development or adoption of a general comprehensive program (program planning) for the prevention and abatement of water pollution and from time to time a review and modification of the program as necessary. Typical of the statements related to program planning is the following from the clean streams law of Pennsylvania (as amended, July 1970). The law states that,

> The board shall have the power and its duty shall be to: --- (2) Establish policies for effective water quality control and water management in the Commonwealth of Pennsylvania and coordinate and be responsible for the development and implementation of comprehensive public water supply, waste management and other water quality plans.

The comprehensive program plan is concerned with transmitting broad goals into accomplishable units of work. The program plan permits efficient organizational staffing and budgeting and development of short and long range work plans. By so structuring a state water pollution control agency through a program plan, the activities of the agency can be geared to the problem at hand and hopefully little effort will be wasted on irrelevant activities.

States have just recently embarked upon comprehensive project planning. This has been in response to federal regulations (18 CFR 601.32 and 33) which state that,

> (a) No construction grant shall be made unless the Commissioner determines, based on information the State, . . . , furnishes to him pursuant to paragraph (b) of this section that a project is included in an effective current basinwide plan for pollution abatement consistent with applicable water quality standards.
>
> (b) In reaching such determination, the Commissioner may require information in such manner as he prescribes concerning the total basin plan, or portion thereof, as he deems adequate to evaluate the effectiveness of the project.

In evaluting the project plans, the Commissioner shall consider whether it adequately covers the following: (1) sources of pollution, (2) volume of discharge, (3) character of effluent, (4) present treatment, (5) water quality effect, and (6) detailed abatement program.

Besides the project planning required by the Environmental Protection Agency (EPA/WQO), state agencies are also involved in some planning activities associated with the Water Resources Commission and with the Department of Housing and Urban Development in their coordination of sewerage system design with overall urban planning. Project planning also involves evaluating the water quality effects of water resources projects. This is especially true in many western states where diversions greatly influence water quality.

Now that state water pollution control agencies are involved in both comprehensive program and project planning, the planning function is demanding more attention in terms of both money and manpower. Also, the large planning effort requires large amounts of information and, consequently, is stimulating a closer look at current data acquisition techniques and practices. The influence of a strong planning effort spreads throughout the agency, and, therefore, illustrates the importance of planning in the overall structure of a state water pollution control agency.

Research

The duty indicated under this general objective is that the state agency will conduct studies, investigations and research with respect to pollution abatement or prevention. The state agency will determine what the research needs are and then either perform the studies with agency personnel or contract with outside organizations (public or private). The research objective also implies that the state agency will coordinate water-quality-related research investigations that are performed by other state or federal agencies. The Wisconsin law will serve as an example of how this duty is stated. The Wisconsin law states,

> The department may conduct scientific experiments, investigations, waste treatment demonstrations and research on any matter under its jurisdiction.

An important aspect of research investigations not delineated in the state laws is the need to follow through on the research results and see that they are put to an effective use. All too often, research results are received by the practitioner and are not utilized by him due to his failure to appreciate the findings. This wastes funds since the research results are not being used to meet the agency's obligations or objectives and it reflects poorly upon the researcher and the state agency. Implementation of research findings should be an important objective of the research function within a state water pollution control program.

Aid Programs

The duty denoted under aid programs is that associated with the accepting and supervising of loans and grants from the federal government and other sources. This involves processing applications and the general administration of the loan or grant. The primary activity would be associated with sewage treatment plant construction grants, but there are also state water pollution control agency support grants, assistance programs under the environmental education act, manpower and training grants of the Environmental Protection Agency (EPA), and facilities grant programs of the Department of Housing and Urban Development (HUD) and Federal Housing Administration (FHA) associated with construction of community sewage works. Also, a duty of aid programs is the need for the state water pollution control agency to certify the need for various other types of projects such as some research grants form EPA and to coordinate water pollution control planning grants obtained under the Comprehensive Water Pollution Control Planning Act, Section 3(c), PL 84-660, as amended and the Urban Planning Assistance Program authorized by Section 701 of the Housing Act of 1954, as amended.

The majority of the activities of this objective will involve the federal government. The California law states this objective in the following manner,

> The state board shall administer any program of financial assistance for water quality control which may be delegated to it by law, and may accept funds from the United States or any person to that end.

The importance of the aid program objective grows as the funding agencies demand more and more information with the applications. As an example, the grant application for sewage treatment plant construction entails the compilation of many statements and certifying letters in addition to the requirement of a project plan;and a review of information supplied with grant applications indicates that the various sections of the state agency must fully cooperate with the aid program function in order for the grant application to be successful.

Technical Assistance

The duty implied by this general objective is to advise, consult, and cooperate on technical matters with other agencies and political subdivisions of the state and federal government and with private enterprises which are polluting the streams. The activities needed to obtain this objective will involve the recommendation of abatement steps for stream standard violators, review of the technical aspects of waste treatment plans and specifications, inspection of new construction of waste treatment plants, recommendation of site approvals for construction of waste treatment plants, inspection of existing waste treatment plants, prediction of water quality effects from projects which change the physical system, and training of waste treatment plant operators. In regard to this objective, the Colorado law states that it is the duty of the state water pollution control agency

> To advise, consult, cooperate, and enter into agreements with other agencies of the state, the federal government, other states, and interstate agencies, and with groups, political subdivision, and industries affected by provisions . . . (of this law) and the policies of the commission.

The law also states that the agency shall have the duty,

> Upon request, to examine and approve or disapprove plans and specifications for the construction and operation by a political subdivision of: New sewerage systems, disposal

> systems, and treatment works; and extensions, modifications of, or additions to new or existing sewerage systems, disposal systems, or treatment works.

Regulation

The duty denoted by this general objective is that the state water pollution control program is responsible for regulating the quality of water in the state's streams and rivers. This objective has traditionally been the most important with respect to the money and manpower devoted to its accomplishment. To better understand the traditional importance, it will be instructive to look at some of the relationships that exist between stream standards and regulation. The Colorado water pollution control program has the following as one of its duties.

> In order to develop the comprehensive program for the prevention, abatement, and control of the pollution of the waters of the state, the division of administration is authorized to recommend the grouping of such waters into classes in accordance with their present and future most beneficial uses in the interest of the public, . . .

This statement very clearly illustrates the general relationship that says in order to establish a control over water quality, the waters must have certain standards of purity. These water quality standards are to reflect the quality of water necessary to meet the beneficial uses of the water. The logical sequence of action, once the standards are established, is to regulate the stream's quality so that it is maintained within the limits set by the stream standards. This is where the general objective of regulation comes into play. South Carolina's law states this in the following manner as a duty of the water pollution control authority.

> Conduct investigations of conditions in the air or waters of the State to determine whether or not standards are being contravened and the origin of materials which are causing the polluted conditions; . . .

This implies some sort of routine monitoring to insure that the stream standards are being met. In summary, then, water pollution control implies stream standards, stream standards imply monitoring, and monitoring suggests that regulation will follow a detected violation of stream standards.

The actual activity of regulation is tied very closely to the concept of permits. Conceptually, regulation involves the following steps.

1. Establishing stream classifications and criteria;
2. Listing pollution sources which violate criteria;
3. Establishing abatement requirements in terms of performance requirements and an implementation schedule.
4. Establishing procedures to assure that future actions (flow depletions or waste additions) do not cause violations.

Steps 1 and 2 are implicit in the water quality standards as discussed above. Step 3 is the point at which a permit is issued or an abatement plan is implemented or both are used. The purpose of the permit would be to set limits on waste discharges at current levels while the purpose of the abatement schedule would be to reduce waste discharges to a level consistent with stream standards. Once this level is reached, the permit may or may not be used. Step 4 is carried out by requiring site approval for future waste treatment plants, requiring the acquisition of a permit to discharge wastes, etc.

If the situation arises where a polluter does not or will not follow the abatement schedule, the regulatory function ends and the legal enforcement function begins. Also, if new discharges fail to follow the established procedures of Step 4, legal enforcement may be required to insure compliance.

Legal Enforcement

The duties denoted by this general objective deal with the enforcement of stream standards by legal means. If the stream standards cannot be maintained by persuasion, the state water pollution control agency must be able to resort to legal means. This therefore must be an objective associated with prevention and abatement of water pollution. Pennsylvania's law states that one of its water pollution control board's duties is to

> Formulate, adopt, promulgate and repeal such rules and regulations and issue such orders as are necessary to implement the provision of this act.

Data Collection, Processing, and Dissemination

The duty denoted by this general objective is mainly that of a support role for the first six objectives. The successful attainment of the first six objectives depends upon good data so the first six objectives may be considered to imply the seventh. However, it is usually spelled out in the laws that data shall be collected. For example, the Colorado law states:

> The commission shall cause samples to be taken from the waters of the state periodically and in a logical geographical manner so as to advise the commission of the water quality standard of the waters of the state.

Data collection involves sampling of a surveillance network, performing special stream surveys, receiving operating reports on waste treatment plants, development of an inventory on the sources of pollution and the water uses, determination of present treatment, evaluation of volume and character of discharge, etc. The primary aim of this study is to evaluate the data requirements placed on the surveillance network and determine the optimum manner in which to obtain this data. Therefore, the main consideration will be the surveillance network data.

The first step is obtaining good water quality data is to select a good representative sample. This should be followed by proper sample preparation and handling and by a form of laboratory procedure quality control. The quality control function of obtaining data must also follow the information through generation of reports by having thorough verification of reported results.

Once a water sample has been taken and analyzed, it must be followed by transmission of the results to a data processing group. Data processing will involve screening, verification, interpretation, indexing, storage, and retrieval of the data. Data dissemination will best be accomplished through the generation of action need reports to be sent to the appropriate part or section of the agency. Data dissemination may also include inventory and data summary reports and special reports. It will be these reports that will keep the entire agency moving toward the objective of prevention and abatement of water pollution.

SECTION V

DATA REQUIREMENTS OF GENERAL OBJECTIVES

The routine collection and analysis of water quality samples is relatively straight-forward when compared to the problem associated with determining in detail what the water quality data is to be used for once it is collected. The establishment of general objectives and work elements was an initial step in the determination of data use within a state water pollution control agency. Figure 1 is a summary of the objectives and work elements.

Delineation of Data Requirements for Each Objective

The purpose of this section is to evaluate the work elements and determine the type of water quality data needed to accomplish the activity efficiently. To accomplish this the basic activities associated with the objectives will be delineated and the information requirements of each activity will be identified. From the list of information requirements, that sub-set derived from the water quality surveillance network will be identified. Rather than detail each objective in this manner, two or three examples will be given and then all the results will be summarized in a table at the end of the section.

Planning

Project and program planning are similar in that a plan for future action is being developed, but they are different in the amount of detail required. Program planning deals with broad definition of programs and work plans and, consequently, does not need specific data on water qualtiy. General, overall trends would best serve the program planning function.

Project planning embodies specific planning related to detailed evaluation of future water quality effects as a result of waste treatment plant location, degree of treatment, number of pollution sources, changing physical stream characteristics, etc. Project planning will be broken down into its various activities for purposes of data requirement identification. This is one of several examples that will serve to illustrate the process.

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In order to identify the water quality data requirements of the project planning function, the planning activities will be structured into three phases, simulation, analysis and evaluation. The activities under each of these phases will be identified and the specific data needs of the activity will be delineated. An outline format is used to illustrate the activities and their data needs.

I. Simulation Phase

  1. Simulate natural hydrologic regime

    a) water quantity
    b) water quality

  2. Simulate economy

    a) Identify water needs versus time
    b) Identify water quality requirements
    c) Identify waste discharge amounts (unconstrained by pollution controls)

II. Analysis Phase

  1. Simulate modified hydrologic regime

    a) Superimpose water demands
    b) Superimpose waste loads

  2. Compare water requirements with modified projection of hydrologic regime

    a) water supply versus time
    b) water quality versus time

III. Evaluation Phase

  1. Formulate alternatives for solving problems identified in II-2.

    a) zoning
    b) water control
    c) pollution control
    d) combinations

  2. Evaluate alternatives in terms of a benefit-cost ratio

Several data requirements are alluded to in the above outline, but to get these into a specific format, each sub-phase of the outline will have its data needs spelled out.

(I-1)
1. historic data on water supply-water quality
2. analytic relations between water supply and water quality

(I-2)
1. population data and projections
2. economic data and projections
3. data and projections on water use, production processes, and wastewater quality
4. effects of artificial changes on analytic relations identified in 2.

(II-1) none

(II-2)
1. projections of water uses (other than economic)
2. water quality requirements of various water uses
3. water volume requirements of various uses

(III-1)
1. information on legal and institutional authorities and limitations
2. information on water storage potential of hydrologic area, etc.
3. information on pollution control technology

(III-2)
1. cost data

When the planning data requirements are looked at in the above manner, several observations can be made. First the planning function requires data from many sources and this data has various degrees of quality. Population growth and economic activity can only be projected in broad generalities; therefore, detailed hydrologic simulation models are rarely of much value in long range projections. The sum of the data for planning is only as strong as its weakest link. Second, the information associated with uncertainty or risk is not readily available. For example, how much risk is associated with DO level fluctuations in terms of effects on fish? It is very difficult to plan action to protect fish when the risks are not clearly understood and the value of such action is not clearly delineated.

The above information outline for planning indicates that many types of water quality information are needed. Of these many types, only the historic water quality data is to be obtained from the water quality surveillance network of sampling stations. The other types (sources of pollution, waste characteristics, effluent volumes, etc.) will be obtained through special inventories or surveys. The current practice of monthly operating reports from waste treatment plants could be expanded to increase the supply of needed information. The permit system, currently under study by many states and the federal government, will supply much of the needed information.

The use of data from sources other than the surveillance network should not obligate the state agency to enter the business of supplying this data. It is logically a duty of the waste discharger to monitor his own operations just as it is the duty of the state to monitor the water quality of streams which belong to the public. This, then, should leave the state agency to collect and analyze only those samples associated with instream water quality. The other data should be collected and stored at the state agency, but the agency should not commit resources to the actual sample taking and lab analysis.

The state must, however, undertake those quality control functions necessary to assure the validity of the data used. This implies state review of (or control over) practices used in collecting, handling, and analyzing samples; and perhaps the occasional splitting of samples or other procedures to verify the overall reliability of the sampling, analysis, and reporting process.

Research

The identification and solution of water quality problems through research demands water quality data of two broad categories. When a state water pollution control agency, through performance of its relevant pollution control activities, meets a situation where it is constrained by limited response options, it must have a means of expanding these options. This will involve research--both technical and non-technical, depending on the situation--which hopefully can study the problem and develop recommendations for expanding the response options. Identification of the limited response situation may occur in a number of ways, but the one of concern here is the identification through analysis of the surveillance network data. This then is one category of water quality data needed by the research function. Identification of limited response situations by other means does not place a direct data demand upon the surveillance network and, consequently, is of little concern in designing the surveillance system.

The other water quality data demand category for research is that associated with the actual performance of the research. This data is usually of a highly specialized nature and is not generally collected by the surveillance network.

The research function, therefore, mainly places a data demand on the surveillance in the form of problem identification. The final decision that research is needed comes from an analysis of the options open to solve the water quality problem.

Aid Programs

The attainment of this objective is primarily administrative in nature, but does require information inputs from other parts of the agency such as the technical assistance section concerning approval of waste treatment plans and specifications and the planning section concerning the section seven grant application. Therefore, the aid program section is not directly concerned with water quality data but is serving as a means to transmit federal influence to the other sections of the agency. The aid program section is primarily concerned with keeping abreast of the federal programs and transmitting their data requirements to the sections responsible for that data.

To elaborate further, under Section 7 of the Federal Water Pollution Control Act (33 U.S.C. 466 et seq) funds are authorized,

> for grants to States and interstate agencies to assist them in meeting the costs of establishing and maintaining adequate measures for the prevention and control of water pollution, . . .

In order to obtain these funds the state must submit to the federal government a plan for the prevention and control of water pollution and have the plan approved. In order to continue receiving funds the state must complete and submit to the federal government a "State Program Grant Application." This application is submitted yearly.

Completion of the application requires information on all aspects of the state water pollution control program. Under "pollution control surveillance and enforcement," the application requires information on water quality standards and compliance, water quality monitoring, effluent controls, inspection of treatment plants, certification of waste treatment plant operators, and enforcement and regulation. This information must be collected from the surveillance and enforcement sections of the agency.

The construction grant applications are more specific in defining the water quality data needed to obtain the grant. The waste treatment plant must be evaluated in terms of its effect upon the water quality of the river. This requires that a water quality data base be established from which such projections can be made. Also, the construction grant application must include information on the other sources of pollution on the streams and the quality of effluent from each. The engineering data required by the construction application requires that the stream standards be evaluated in terms of the effect the project will have upon them.

The collection of water quality data for the purpose of grant applications should not entail extra effort since much of the required data can be obtained from the routine monitoring. There may be a need for special surveys if the stream being considered has not been monitored very often.

After completion of a waste treatment plant under the construction grant program, the state must inspect the plant at least annually for three years and then as often as specified in the State Program Plan submitted under Section 7 of the Federal Water Pollution Control Act.

Technical Assistance

The need for technical assistance also carries the need for valid data upon which technical decisions can be made. Technical assistance must necessarily be involved in the following.

I. Waste Treatment Plant Construction
    1. waste treatment plant site approvals
    2. waste treatment plant plans and specification approval
    3. inspection of new construction

II. Waste Treatment Plant Operation
    1. inspection of plant operation
    2. training plant operators

III. Abatement Recommendations for Stream Standard Violators
    1. process modification recommendations
    2. waste treatment plant construction recommendations
    3. legal testimony

Major data requirements and their sources for the above duties are as follows.

(I) Historical record necessary to compute future water quality effects as related to plant location and design criteria. This implies determination of the stream's condition with respect to effluent added and treatment needed.

(II) Review of waste treatment plant operating reports as related to stream water quality indicated by suveillance network.

(III) Historical record of stream quality as related to possible process modifications or waste treatment alternatives.

The use of historical record to establish models of river or stream water quality for the purpose of abatement procedure planning is quite similar to the establishment of water quality models for the purpose of planning for water pollution prevention. Both involve the prediction of future effects. The main difference lies in the fact that planning for abatement is concerned with a specific polluter on a specific stream at a specific time. Planning for prevention concerns a more general plan which must provide guidelines for future action at all levels of pollution control activity and for all streams in the state. The implications are that the models developed for prevention planning could be refined to a more specific nature and used for abatement planning in the area of technical assistance. This may require more specific data obtained by special surveys.

The maintenance of control over the operation of waste treatment plants will require routine evaluation of both surveillance data and operating reports from the waste treatment plants themselves. Periodic inspection of plant operation will also be necessary to insure the reported conditions are correct. Routine evaluation of the surveillance network data is accomplished through a regulation section, but stream standard violations must be traced down by an analysis of the waste treatment plant operating characteristics. This requires close coordination between routine surveillance and operation of waste treatment plants.

Regulation

Regulation entails the routine surveillance of water quality to insure that the stream standards are being met. This has been and is to a large extent today the main reason for collecting instream water quality. To accomplish this objective, the water quality data from the surveillance network serves to:

I. Determine compliance and noncompliance with water quality standards.

II. Evaluate progress of the abatement program toward meeting standards.

III. Identify emerging water quality problem areas so that prevention can be effected rather than abatement at the last moment.

The type of data necessary to insure compliance is determined by the stream standards in effect for the particular body of water sampled. The quantity of data needed depends upon the fluctuations in water quality present in the stream. A statistical analysis, including modeling of stream quality fluctuations, will determine the frequency of sampling required to adequately determine the instream water quality.

In general, regulation data will be reviewed after the lab results are reported, and if compliance is indicated the data is stored. Once stored, the data is, in effect, partly establishing the historical record nedded to meet other objectives. If noncompliance is noted, the data should immediately promote abatement action within the agency. The data will again be stored, but it may later be reviewed in terms of abatement progress of a polluter. If the data indicate that stream quality is near noncompliance, this may promote prevention action within the agency.

Basically, the data used for regulation is serving to put into action those parts of the state agency needed to keep stream quality within the set limits. Beyond this purpose, the data has no direct use for meeting immediate regulation objectives. The main problem associated with data for regulation purposes is the tendency to let data collection become an end in itself and the neglect of emphasis on followup action. Hopefully, by keeping the general objective of regulation in perspective, its data requirements can be optimized and more effort devoted to the other objectives of a state water pollution control agency. This optimization of data collection for regulation purposes will necessarily involve the statistical analysis mentioned earlier.

Legal Enforcement

Water quality data needs of this section are mainly those associated with proving stream standard violations in court. The data used for this purpose can be better utilized by channeling it through other sections of the agency such as technical assistance or regulation. This provides for a technical evaluation of the raw data and puts it in a more relevant form for the purpose of legal action. The actual data needs of legal enforcement may be of a more detailed nature than that which routine monitoring would supply. This may result in special surveys to verify that certain conditions do exist beyond the shadow of a doubt.

Summary

In Figure 2, the work elements are listed under each objective and the water quality data requirements of each work element are summarized using a broad classification system. The water quality data needs are broken down into waste discharge data and stream quality data. Each of these is in turn evaluated as to volume, character, and variability. The last column summarizes the data needs as related to a routine monitoring network. This does not include effluent monitoring, but the waste discharge data classification was included to illustrate the total water quality data need. This emphasizes the fact that not all water quality data needed by the agency comes from a routine surveillance network, i.e., stream quality monitoring.

By using Figure 2 as a summary of the previous discussion, the overall water quality data needs of a state agency can be visualized. The classification of data needs shown in Figure 2 consists of four divisions: 1) Specific--specific parameter data bits with high precision (±10% to 0%); 2) General--trends, means, etc., of flow, dissolved oxygen, temperature, TDS, etc., with a range of precision from order of magnitude to ±10%; 3) Index--information that can be used to estimate general data (basically this is qualitative information); 4) None--a general indication that no direct input of routine water quality network data is needed. This summarization technique will permit a general correlation between data needed and the various data gathering techniques.

	Data Needed on Waste Discharges			Data Needed on In-Stream Quality			Summarized Surveillance Network Data Demand
	Vol	Char	Var	Vol	Char	Var	
Prevention							
A. Planning							
- Program Planning	G	G	G	G	G	G	General
- Project Planning	G	S	G	S	G	G	General
- Planning Coordination	G	G	G	G	G	G	General
- Contingency Planning	I	I	I	I	I	I	Index
B. Research							
- Develop Research Needs	S	S	S	S	S	S	Specific
- Approve Research Proposals	-	-	-	-	-	-	-
- Evaluate Progress of Sponsored Research	-	-	-	-	-	-	-
- Research Coordination	G	G	G	G	G	G	General
- Conduct In-house Research	-	-	-	-	-	-	-
C. Aid Programs							
- Grant and Loan Administration	-	-	-	-	-	-	-
- Coordination of Grants and Loans	-	-	-	-	-	-	-
Abatement							
A. Technical Assistance							
- Approve WTP Plans & Specifications	S	S	S	S	S	S	Specific
- Inspect New Construction	-	-	-	-	-	-	-
- Recommend WTP Site Approval	S	S	S	S	S	S	Specific
- Train WTP Operators	-	-	-	-	-	-	-
- Inspect WTP Operations	S	S	S	S	S	S	Specific
- Recommend Abatement Steps for Polluters	S	S	S	S	S	S	Specific
B. Regulation							
- Issue Permits	S	S	S	I	I	I	Index
- Approve WTP Sites	S	S	S	S	S	S	Specific
- Develop Abatement Schedules for Polluters	S	S	S	S	S	S	Specific
- Review Stream Standards	S	S	S	S	S	S	Specific

Figure 2. Summary of Data Needs as Related to the Work Elements.

	Data Needed on Waste Discharges			Data Needed on In-Stream Quality			Summarized Surveillance Network Data Demand
	Vol	Char	Var	Vol	Char	Var	
- Recommend Changes in Regulation	S	S	S	S	S	S	Specific
- Initiate Further Internal Action for Persistant Polluters	-	-		-	-	-	-
C. Legal Enforcement							
- Issue Cease and Desist Orders	S	S	S	S	S	S	Specific
- Conduct Hearings	-	-	-	-	-	-	-
- Prepare Briefs for Court	S	S	S	S	S	S	Specific
- Initiate Court Action	-	-	-	-	-	-	-
- Prepare Laws and Regulations	S	S	S	S	S	S	Specific
- Levy and Collect Fines	-	-	-	-	-	-	-

Figure 2. (Continued)

SECTION VI

STATE-OF-THE-ART SUMMARIES

Three major classifications of data acquisition techniques are considered in this study. These are grab sampling, automatic monitoring, and remote sensing. A state-of-the-art paper has been prepared for each technique, and all three are included in the Appendices. This section will serve to present a short summary of each technique's state-of-the-art. Each state-of-the-art paper has its references presented at the end of the paper.

Development of a state-of-the-art paper is dependent upon the published material available. For the established technique of grab sampling, the available literature is rather small. This is primarily due to the assumed simplicity of the sample collection. This assumption comes from a lack of sophistication in grab sampling and, consequently, a rendering of the technique less effective than it could be. Hopefully, the results of this report will indicate the increased effectiveness of a planned grab sampling surveillance network.

Both automatic monitoring and remote sensing are developing technologies, and there is a large amount of published material related to the various development steps. Also new and unique applications warrant published articles, thereby increasing the volume of published material. The volume of literature for automatic monitoring and remote sensing, therefore, permits the development of more realistic state-of-the-art papers. However, the volume of material also requires decisions as to relevance which are sometimes difficult to make.

Because of the rather small amount of literature dealing specifically with grab sampling, many general articles that relate to data collection in general (and, consequently, grab sampling) have been reviewed in the grab sampling paper. These articles could be included in all the papers, but since the other two techniques have considerable literature available, it was decided not to repeat the reviews.

Grab Sampling Summary

Literature available on the design of routine grab sampling water quality surveillance networks, as noted above, is quite small. The available literature either speaks

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of surveillance system design in very general terms or it dwells upon the actual grab sampling procedures. This leaves the questions related to sampling station location, number of stations, sampling frequency, and parameter measurements unanswered.

The grab sample state-of-the-art paper in Appendix A first reviews the papers which relate data acquisition to a specific function of a water quality management agency. This includes reviews of papers which relate the data needs of planning, legal proceedings, abatement, etc., to general suggestions for improving the ability of the data to satisfy that need.

Next, papers are reviewed which attempt to identify those parameters that should be measured by a grab sampling network. This identification is the result of reviewing stream standards, or the planning process. It also occurs through the creation of an index. Some parameters may be eliminated through correlation with a similar parameters.

Sampling frequency and number of stations are usually discussed at the same time. It seems to be generally agreed that more samples from fewer stations is more desirable. It is also agreed the sampling frequency depends upon the variability of the constituent to be analyzed. The events, therefore, that cause variability of a constituent are discussed as having an influence on the frequency of sampling.

There is little specific information on sampling station locations. Each situation presents a different set of conditions, therefore, it is quite difficult to develop a set of hard and fast rules.

Grab sampling procedures have received considerable attention in the literature; however, this literature is specifically related to in-stream sampling, sample preservation, sample storage, and sample analysis. Few articles appear which attempt to relate all factors in an overall design for a grab sampling surveillance system. Current developments occurring in water quality laboratory analysis procedures could have a profound effect upon the grab sampling method of data collection. The cost of analyzing samples presents a huge barrier to increasing sampling; therefore if the laboratory analysis costs could be reduced (through sample analysis automation) this could greatly affect any cost-effectiveness analysis which attempts to relate grab sampling to other data acquisition techniques. For this reason articles pertaining to grab sampling procedures are reviewed but not with the depth given other aspects of grab sampling system design. However, whenever a grab sampling system is created there must be good system design and good sampling and analysis procedures if good, meaningful data is to be acquired.

Cost of grab sampling is an elusive piece of information. Almost no information appears in the literature. Estuary sampling provides the designer of a surveillance system with a different situation from that of streams. The mixing of fresh and saline waters along with the complex hydrologic and hydrodynamic characteristics of an estuary have been the target of many papers on sampling.

Automatic Monitoring Summary

As noted earlier, much of the literature on automatic monitoring revolves around new technical developments or new applications of existing equipment. The state-of-the-art paper in Appendix B reviews these articles by classifying them into applications at various levels of government and in university research. For purposes of this summary, Table 1 displays all the applications and their pertinent facts in a very condensed form.

Beyond application oriented literature, there has been discussion of the ability of automatic monitors to satisfy the data needs of its users. Automatic monitoring provides high frequency sampling and real time data; however, it is expensive and it is quite limited in the number of parameters that can be measured reliably. A breakdown of the ability of automatic monitoring data to satisfy various functions within a water quality management agency depends upon the function. For planning purposes, the parameter limitation is quite restrictive. For abatement purposes the real time data is extremely valuable.

The present instrumentation suffers from a lack of adequate sensors, and there appears to have been little work in this area. The actual recording and processing of the data appears to be the strongest link in the current automatic water quality data acquisition system because it is fully developed and relatively trouble free. The lack of adequate sensors is due to the rough field conditions under which they must operate (they were originally designed for process control where an ideal environment can be maintained). The sensor problem carries over into a maintenance problem once the unit is in the field. Weekly service is highly recommended for the units. Future needs point heavily toward more sensors which are reliable.

Cost information on automatic monitors is available since many systems are currently being sold, installed, and operated. Costs of each monitor run from $6,000 to $12,000 depending upon the technique of data recording and the sensors involved. Computers can be added to accept the data and control the monitor. Since the units require considerable maintenance, this is a critical cost factor.

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TABLE 1. Application of Automatic Monitors

System Name and/or Agency Involved	Where Employed	When Employed	Type of Water Sampled	Number of Stations	Type of System	Parameters Measured	Recording Technique	Purpose	Data Use	Reference Source(s)
USGS	Delaware Estuary	1955--	Estuarine	8	In situ	DO, pH, Cond, T, Turb, S Rad, Cl, Stage, ORP	Strip chart w/o telemetry & ppt.	Suppl. grab sa. program. Detect rapid flucuations in w.q.	Regulation: Water & Waste Treatment control	McCartney and Beamer, 1962 Keyser, 1964
USGS	Patuxent River Estuary	1963--	Estuarine	1	In situ	T, DO, Cond, Turb, Stage	Strip chart w/o telemetry	Suppl. grab sa. program. Rapid flucuations & Diurnal variations	Research: Effects of thermalpollution on biological life of estuary	Cory and Davis 1965. Nauman and Cory, 1970
EPA/WQO	Potomac River & Estuary	--	Freshwater & Estuarine	4	In situ	DO, T, Cl	Telemetry	Provide real time continuous records of w.q.	Planning: mathematical models	McDermott, Ballinger and Sayers, 1968
EPA/WQO	New York Harbor	1963--	Freshwater & Estuarine	5	In situ	pH, Cond, T DO, Turb, ORP, S Rad	ppt at the site & telemetry/twls & ppt	Historical, continuous records of water quality	Planning: mathematical models	Bromberg and Carames, 1970
EPA/WQO	Hudson-Delaware Basin	--	Freshwater & Estuarine	--	Mobile Van	--	--	Collect w.q. data in remote areas	--	Dewling, 1969
EPA/WQO	Oregan	1968--	Freshwater	3	Mobile Trailer	pH, Cond, DO, T	Strip chart w/o telemetry	--	--	O'neal, 1971
EPA/WQO & Metro. St. Louis Sanitation District	Mississippi River in Missouri	--	Freshwater	--	Mobile Boat	DO, T, Cond, pH	--	Determine extent of pollution in 100 mi. stretch of Mississippi R.	Regulation: Water & Waste treatment control	Anon., 1969
Bureau of Reclamation	Calif. Cen. Valley Project	1965--	Freshwater & Estuarine	--	Mobile Trailer	Cond, T, Turb, DO, pH, S Rad	Strip chart w/o telemetry	Collect w.q. data in remote areas. Determine flucuations in salinity	Regulation: Water quality to control quality. Planning: New reservoir(s)	Anon., 1967 Marks, 1966
Ohio River Valley Water Sanitation Commission (ORSANCO)	Ohio River Valley	1960--	Freshwater	27	In situ & 1 Mobile	pH, T, Cond, DO, Cl, ORP, S Rad	Tele/ppt & Computer control & processing	Suppl. grab sa. program with realtime system	Regulation: Evaluate pollution control efforts	Cleary, 1962 Klein et al., 1968

TABLE 1. Continued

System Name and/or Agency Involved	Where Employed	When Employed	Type of Water Sampled	Number of Stations	Type of System	Parameters Measured	Recording Technique	Purpose	Data Use	Reference Source(s)
Interstate Commission for the Delaware River Basin (INCODEL)	Delaware River Basin	1959--	Freshwater & Estuarine	12	In situ	T, pH, Cond, DO, Turb	Strip chart w/o telemetry	Suppl. grab sa. program	Planning: Mathematical models	Parker, 1961 Smith and Morris, 1969
Empire State System	New York State	1966--	Freshwater	12	In situ	pH, Cond, DO, T, Turb, Stage Cl, F, S Rad.	Telemetry/ Computer Control & Processing	Suppl. grab sa. program & provide rapid intelligence system to protect state waters	Regulation: Water & Waste treatment control Planning: Mathematical Models	Maylath, 1970a Maylath, 1970b
New Jersey State Dept. of Environ Protection & USGS	New Jersey	1968--	Freshwater	10	In situ	Cond, T, pH, Turb, DO	ppt w/o telemetry	Suppl. grab sa. program	Planning. Trends in w.q.	Anderson et. al., 1970
Pennsylvania Dept. of Health	Pennsylvania	1965--	Freshwater	2	In situ	pH, Cond, T	ppt & printer w/o telemetry	Supply data on Acid mine drainage	--	Mentink, 1970
Wisconsin Dept. of Natural Resources	Wisconsin	1968--	Freshwater	--	Mobile Trailer	T, DO, pH, Cl, ORP, Cond, S Rad	Strip chart w/o telemetry	Suppl. grab sa. program. Special surveys, diurnal variations	Regulation: Formulate stds. Locate pollution source Research:	Anon., 1968 Schaufnagel, 1971
Wisconsin Dept. of Natural Resources	Wisconsin	1970--	Freshwater	11	In situ	DO, T, pH, Turb	Telemetry/ Computer Processing & control	--	--	Anon., 1968 Schaufnagel, 1971
Dept. of Ecology State of Washington	Washington State	1969--	Freshwater	--	Mobile Trailer	DO, T, Cond, Turb, pH, Cl	--	Collect Historical data	--	Palko, 1971
Texas Water Pollution Control Board	Galveston Bay	1963--	Estuarine	--	Mobile Boat	DO, Cond, pH, T	--	Determine affects of Indus. & Munic. pollution of w.q. & fish	Planning: Water pollution management	Davis, 19[illegible]

TABLE 1. Continued

System Name and/or Agency Involved	Where Employed	When Employed	Type of Water Sampled	Number of Stations	Type of System	Parameters Measured	Recording Technique	Purpose	Data Use	Reference Source(s)
Greater Chicago's Metropolitan Sanitation District	Chicago, Ill.	1968--	Effuent & Freshwater	11	In situ	DO, T, Cond, pH, ORP, Cl, Turb, S Rad	Strip chart ppt & twls	Obtain a better appraisal of w.q. conditions	Regulation: Water & Waste treatment control	Lanyonand Kurland, 1971
Detroit Sewer Monitoring & Remote Control System	Detroit, Mich.	--	Collection system	--	In situ	--	--	Better understand behavior of sewer & drainage systems	Regulation: water & waste treatment control	Sahre, 1970
University of North Carolina	Chapel Hill, N.C.	1960--	Freshwater Reservoir	1	Submersible	T, DO,	Telemetry/strip chart & ppt	Study material transfer through metalimnion in impoundment reservoirs	Regulation: Water Impoundments	Weiss and Oglesby, 1963
Georgia Institute of Technology	Georgia	--	Freshwater	--	Mobile Van	DO, T, Cond, Turb, Stage, Depth, S Rad	Strip chart w/o telemetry	Study the affects of storms on w.q.	Research: Relation between water flow & quality	Ingols, 1970
Ontario Water Resources Commission	Lake Erie	1969--	Freshwater	2	Immersion	pH, T, Cond, Turb, Depth, Current (velocity & direction)	Magnetic tape	Determine the dispersion characteristics for near shore areas of Great Lakes	Planning: Mathematical Models	Palmer and Izatt, 1970 Palmer, 1970

Abbreviations

N.C. = North Carolina
Ill. = Illinois
Mich. = Michigan
EPA/WQO = Environmental Protection Agency/Water Quality Office
USGS = United States Geological Survey
Metro = Metropolitan
# = number
ppt = punched papertape
w.q. = water quality

twls = typewritten log sheet
stds = standards
Suppl. = Supplement
sa. = sampling
R = rivers
mi = miles
w/o = without
indus = industial
munic = municipal
Calif. = California

Cen = Central
pH = negative log of hydrogen ion activity
DO = dissolved oxygen
T = temperature
Cond = Conductivity
ORP = Oxidation reduction potential
Cl = Chlorine (Dissolved Chloride)
Turb = turbidity
S Rad = Solar Radiation
F = Fluoride

Remote Sensing Summary

Aerial remote sensing data acquisition techniques add to but do not replace, existing field and laboratory analysis methods. Laboratory methods, which depend on the use of test tubes, water-sample bottles, and microscopes, are made even more valuable. Critical areas that require field work can be located more rapidly and accurately. Both time and money can be saved by reducing field work, leaving more of both for confirming laboratory analyses and, more important, for coordinating and taking corrective actions.

The available remote sensing techniques can generally be classified into four major categories: 1) visible range, 2) thermal infrared, 3) microwave, and 4) multispectral sensors. Color aerial photography (visible range) holds high present potential for actual identification of kinds, concentration, and distribution of pollutants. Furthermore, color aerial systems are the least expensive and most versatile of all aerial remote systems to use. Unfortunately, interpretation has been historically more of an art than quantitative measurement. It has been demonstrated that concentration distributions of pollutants can be derived from color aerial photos if appropriate ground correlations are made. The success of aerial photographic systems is dependent upon two considerations:

1. Do pollutants and water quality parameters affect light sufficiently to extract desired information; and

2. Can remote sensing techniques be combined with analytic procedures to extract available information.

Many investigators have used aerial thermal infrared systems to very accurately determine the surface temperature of water bodies. Temperature perhaps is the most quantitative parameter presently capable of measurement with remote sensors.

The great value of data collected with thermal systems is its conjunctive use with other methods of aeiral surveillance, such as color photography and coordination with ground data.

Remote sensing apparatus, using the microwave region, has successfully been applied in accurately measuring surface water temperature through clouds and precipitation. The microwave region has been used to measure the extent and thickness of oil slicks with respectable success. However, care must be exercised when this technique is used, because weather conditions and sea state can render oil slicks invisible.

Multispectral remote sensing systems hold the greatest potential for actual distinguishing and determination of pollutants. As is shown and discussed in Appendix C, each pollutant differs spectrally from other pollutants at one or more corresponding wavelengths. The procedure then is to choose the interval, or intervals, at which the greatest differences exist. By comparing spectral signature data catalogs and ground data, various kinds and concentrations of pollutants may be identified with reasonable certainty and accuracy.

The cost of remote sensing equipment is quite high. Actual purchase of equipment with a reasonable degree of sophistication quickly runs into a few hundred thousand dollars. If larger aircraft are employed with highly sophisticated electronic systems, costs may easily run into millions of dollars. For state water pollution control budgets a contract basis appears to be the only feasible means to apply remote sensing. There are no reported applications of remote sensing by a state agency on any routine basis.

SECTION VII

DESIGN PROCEDURE FOR WATER QUALITY SURVEILLANCE SYSTEMS

In developing a design procedure which can be applied under different conditions in different states, considerable flexibility must be incorporated into the procedure. This flexibility must take into account the different program objectives, the various capabilities of different agencies and the influence of interrelationships between such factors as number of sampling stations and frequency of sampling. To contain the desired flexibility, the design procedure must permit the input of descriptive parameters so that each agency can designate its priorities, strengths and limitations.

Pollution Control Strategies

The strategy a state water pollution control agency uses to control water quality has a very large influence upon the type of data required for the agency to function properly. For example, a state with little resources may tend to be crisis oriented, waiting for the pollution crisis to arise before acting. This, in effect, would require no routine monitoring since the crisis would identify itself by the fact that it is a crisis. On the other hand, a state may choose to concentrate on planning to solve its water quality problems--implying the end justifies the means. This would indicate a data need of general water quality trends. Or a state agency may be interested in only enforcing its stream standards. If the stream quality is to be the primary source of information on regulation, then a strong surveillance program is indicated. But if the stream quality is only to be an indicator while effluent control is to be the primary aim of regulation, then the surveillance network need only indicate trends.

The above examples may indicate the extremes, but at the same time they do illustrate the fact that the strategy a state chooses will largely determine the general form of its surveillance network. Therefore, for a set of design guidelines to be developed which can be used under all strategies, a way of classifying a state's strategy must be delineated.

The general policies of pollution control, prevention and abatement yield a natural division of a state agency's control efforts. Looking at Figure 2, we see that a prevention strategy largely needs general data which implies one type of surveillance system, while an abatement strategy needs specific data which denotes a more intensive surveillance effort than that for planning. Within prevention, an agency may choose to emphasize planning over research, thereby eliminating any specific routine surveillance data needs for the prevention effort. Under abatement, an agency may use permits as a means of regulating water quality, thus putting the main responsibility for information reporting upon the polluter. This strategy would require only general indications on stream quality to insure that the strategy is working. The surveillance system would not be used as a means of catching polluters as it would be if the strategy was only to approve waste treatment plant sites as a means of regulating water quality. Under this strategy it would be the agency's responsibility to prove the pollution event can be traced to a certain outfall. This would demand a comprehensive surveillance network.

Using the above line of reasoning, a state agency can use Figure 2 as a means of determining where it is currently putting its main emphasis and once this is known, the agency can use the appropriate guidelines in the development of a surveillance network. Strategy determination can be accomplished by either of two methods. The first was would be to look at the various program elements in an agency's budget and determine what percentage of its funds go to each objective. If it is not difficult to relate budget items to the objectives, this method of strategy determination is the more simple and may be more accurate.

The second method that is proposed to determine the strategy of an agency is to establish a chart containing the objectives and their associated work elements. The object of the chart is to allow agency personnel to check the appropriate level of activity under each work element (see Figure 3). Each level of activity has a number of points associated with it and this number is to be placed in the point column. The points are totaled for each objective and then for prevention, abatement and program control. The total possible points for each objective level is the same; consequently, the points can be used to compare the involvement of the state agency in each objective. Likewise, the totals for prevention, abatement, and program control are comparable. If an agency had the same level of activity in all areas, the point totals would be identical. Obviously, very few states, if any, would have identical point totals; therefore, the state agency can evaluate from the varying point totals whether it is putting the emphasis on the function it intended to. This may reveal areas where increased or decreased emphasis should be placed.

It makes no difference which strategy determination method is used. The main point is that an agency's strategy has a large

	Activity Level				
	High	Med	Low	None	Points
Prevention					
A. Planning	30	20	10	0	
- Program Planning	___	___	___	___	___
- Project Planning	___	___	___	___	___
- Planning Coordination	___	___	___	___	___
- Contingency Planning	___	___	___	___	___
B. Research	24	16	8	0	
- Develop Research Needs	___	___	___	___	___
- Approve Research Proposals	___	___	___	___	___
- Evaluate Progress of Sponsored Research	___	___	___	___	___
- Research Coordination	___	___	___	___	___
- Conduct In-House Research	___	___	___	___	___
C. Aid Programs	60	40	20	0	
- Grant and Loan Administration	___	___	___	___	___
- Coordination of Grants and Loans	___	___	___	___	___
	Total for Prevention				-----
Abatement					
A. Technical Assistance	20	13	7	0	
- Approve WTP Plans and Specifications	___	___	___	___	___
- Inspect New Construction	___	___	___	___	___
- Recommend WTP Site Approval	___	___	___	___	___
- Train WTP operators	___	___	___	___	___
- Inspect WTP Operations	___	___	___	___	___
- Recommend Abatement Steps for Polluters	___	___	___	___	___
B. Regulation	20	13	7	0	
- Issue Permits	___	___	___	___	___
- Approve WTP Sites	___	___	___	___	___
- Develop Abatement Schedules for Polluters	___	___	___	___	___
- Review Stream Standards	___	___	___	___	___
- Recommend Changes in Regulations	___	___	___	___	___
- Initiate Further Internal Action for Persistent Polluters	___	___	___	___	___

Figure 3. Strategy Evaluation for State Water Quality Management Programs.

	Activity Level				
	High	Med	Low	None	Points
C. Legal Enforcement	20	13	7	0	
- Issue Cease and Desist Orders	—	—	—	—	—
- Conduct Hearings	—	—	—	—	—
- Prepare Briefs for Court	—	—	—	—	—
- Initiate Court Action	—	—	—	—	—
- Prepare Laws and Regulations	—	—	—	—	—
- Levy and Collect Fines	—	—	—	—	—
Total for Abatement					-----
Program Control					
A. Information Collection	40	27	13	0	
- Surveillance Network	—	—	—	—	—
- Field Investigations	—	—	—	—	—
- Other Sources	—	—	—	—	—
B. Information Processing	20	13	7	0	
- Screen	—	—	—	—	—
- Verify	—	—	—	—	—
- Interpret	—	—	—	—	—
- Index	—	—	—	—	—
- Store	—	—	—	—	—
- Retrieve	—	—	—	—	—
C. Action Initiation	30	20	10	0	
- Action Need Reports	—	—	—	—	—
- Inventory and Data Summaries	—	—	—	—	—
- Special Reports	—	—	—	—	—
- Publicity	—	—	—	—	—
Total for Program Control					-----

Figure 3. (Continued)

influence upon the design of the appropriate surveillance system and, consequently, the strategy must be known.

Stream Characterization

In the logical development of a surveillance system, there must be consideration given to two major elements: 1) the strategy of the agency and 2) the character of the stream. Characterization of a stream will basically involve a determination of water quality patterns along the stream. This will necessarily involve the utilization of many types and large quantities of information. There must be an identification of the more important parameters and the variation of these parameters over the length of the stream. Since flow has a large influence on quality, this parameter should definitely be included. Ideally, there should be a complete inventory of the stream's water uses and of its waste outfalls and a survey of the natural or uncontrollable pollution sources. This would provide a basis for determining the critical pollution parameters for that stream, and it would help in relating pollution variation to flow patterns. The word "ideally" was used because unfortunately, inventories of water uses, waste outfalls, and natural conditions are not readily available in all states. Hopefully, as the emphasis on effluent controls spreads, the needed inventories will be developed. The use of a permit system appears to be an excellent way to obtain the needed information with a minimum amount of effort on the part of a state agency.

The water quality data to be used in the characterizations can be obtained from many sources. Some of these are the state water pollution control agency's data books, water treatment plant records, local health department files, or special surveys performed as a comprehensive analysis of a particular stream's situation. A statistical analysis of the data can provide information on the variation of the water quality. Flow data may or may not be available in an agency's records and, consequently, other sources of this information may be required. U.S. Geological Survey (USGS) records may provide the flow information needed.

The information needed for the inventory of waste outfalls, if not readily available, may be obtained through use of an aerial survey, a review of industries listed in a telephone book or business directory, or by an actual walking of the river. Also, special stream surveys usually supply some of this information.

Plotting the above information on a river-mile graph permits rapid visualization of the existing water quality situation. Plotting may only be necessary on the more complex streams, whereas a simple review of the data may suffice on shorter, less developed streams. The information now available, along with stream standards, can provide a good indication of where the sampling stations should be located and it permits general determination of sampling frequencies. In other words, sampling frequencies need to be higher near high pollution centers. Also, at this point the strategy of the agency must be considered. A strategy requiring only trend data may dictate low relativeity frequencies everywhere.

Relation of Pollution Control Strategy to Data Acquisition Strategy

Before any detailed design of a surveillance system can take place, the strategy of the agency must be related to the general data acquisition approach. The assumption is made, however, that every state agency will monitor a very "skeleton" network in order to justify the organization's existence in terms of budget requests versus accomplishments. The skeleton network could consist of whatever monitoring level the agency feels is needed to verify its success or failure in controlling a state's water quality. In general the skeleton network would consist of sampling stations at state lines on the major streams and stations below major population centers in order to insure stream standards are being met. Location of these skeleton stations would not require the stream characterization.

Data acquisition beyond the skeleton network will depend upon the agencies' pollution control strategy as depicted in Figure 4. An emphasis on prevention would indicate a need for general data that may be collected by either routine monitoring, special surveys, or both. An emphasis on program planning over project planning would indicate a need to emphasize routine monitoring over special surveys. This results from the fact that program planning uses trend data to a greater extent than project planning.

Abatement has basically three data acquisition strategies. If a state emphasizes permits as its abatement tool, the waste treatment plant operating reports can be the prime source of water quality data. The other means of data acquisition are special surveys and routine monitoring. This is not to say that these three strategies are all the data acquisition means available. A state could support a public report system whereby a citizen reported any water pollution

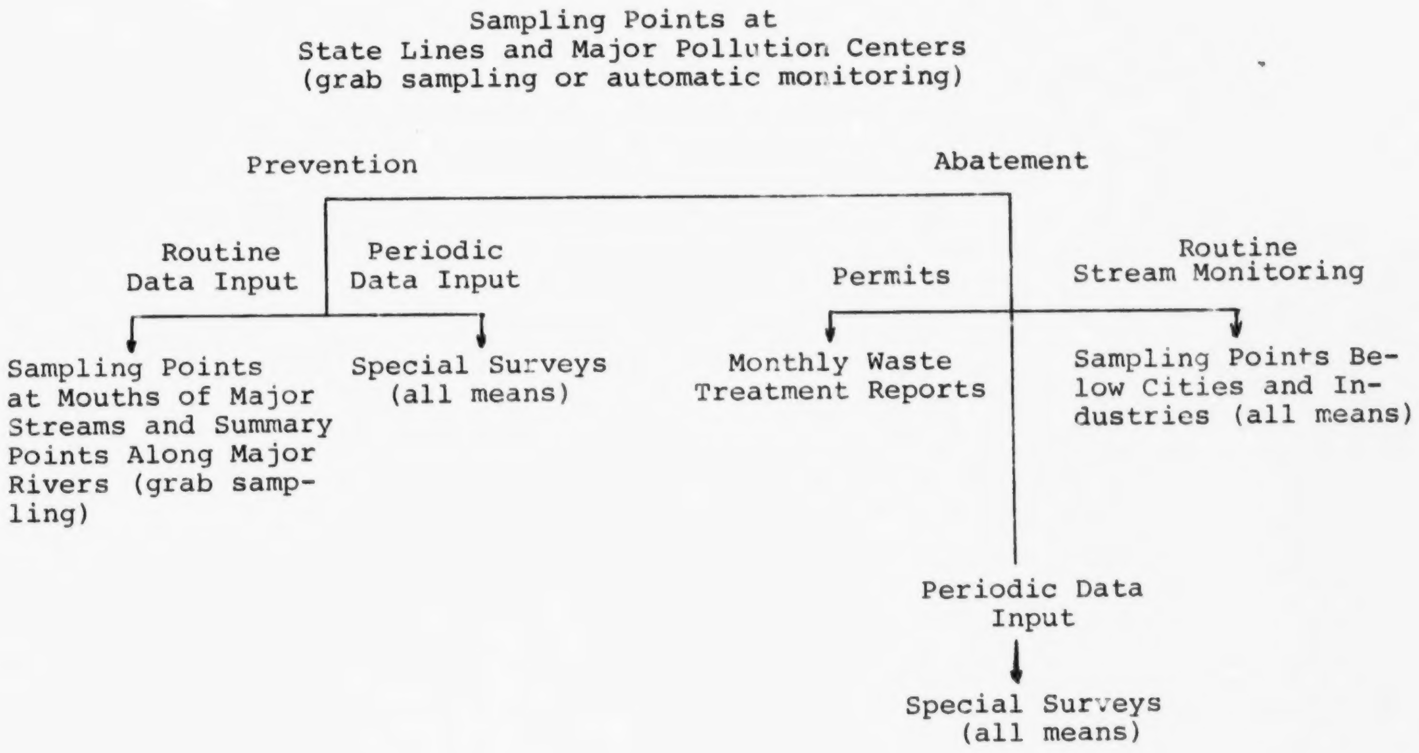
Sampling Points at
State Lines and Major Pollution Centers
(grab sampling or automatic monitoring)
Prevention
Abatement
Routine Data Input
Periodic Data Input
Permits
Routine Stream Monitoring
Sampling Points at Mouths of Major Streams and Summary Points Along Major Rivers (grab sampling)
Special Surveys (all means)
Monthly Waste Treatment Reports
Sampling Points Below Cities and Industries (all means)
Periodic Data Input
Special Surveys (all means)

Figure 4. Pollution control strategy associated with data acquisition strategy.

event he witnessed. However, this would be a strategy supplemental to the basic data acquisition system.

The foregoing discussion was designed to emphasize the fact that routine monitoring is only one way to input water quality data to a water pollution control agency. So before a state jumps into the design of a routine monitoring surveillance system, it must first decide that it has chosen the right data acquisition strategy for its pollution control strategy. The choice of one strategy over the other is difficult to make since there are advantages and disadvantages with each one. Currently the arguments are centering around permits at both the Federal and state levels. It is not the purpose of this project to enter into the various controversies, but to design a routine surveillance system. At the same time, however, it is realized that the final total information acquisition program will probably be a combination of various information acquisition techniques.

Surveillance System Design

The design of a surveillance network is dependent upon whether the network is to be used primarily for prevention or abatement (see Figure 4). This difference will be reflected in the sample station location, sampling frequency and sampling techniques. In order to make valid comparisons on effectiveness and cost, a grab sampling network will be designed first and then automatic monitors and remote sensing will be evaluted as a way to provide the same information at reduced costs.

In designing the grab sampling network, stream's characterization (quality parameters of consequence, flow, waste outfall inventories and stream standards applicable to the stream) can be used to determine a set of sampling locations consistent with the state strategy. This establishes a basis upon which to analyze the sampling frequency. The important aspect of frequency is the cost involved; therefore, there needs to be a way for a surveillance system manager to compare cost against effectiveness. Under stream simulation, a way to relate frequency to effectiveness will be developed and this can then be related to cost. The manager can then make rational decisions based on cost-effectiveness rather than on pure logic.

Stream Characterization Procedures

To design a monitoring system for a stream, the individual characteristics of the stream must first be known. This will permit determination of the sample station location and the parameters which need to be measured. The following is a list of the activities needed to characterize a stream.

I. Collection of existing water quality and quantity data for the stream

II. Plotting the flow and quality values on a river-mile graph

III. Indicate location on the graph of the waste outfalls and determine the waste load imposed on the stream (volume and contents). This will require a waste outfall inventory

IV. Indicate on the graph the stream standards in effect for various reaches of the stream

V. Locate sampling stations at indicated problem areas according to state strategy

   1. Prevention--place sample station location at the critical quality point along the stream. The routine monitoring data will then give a general indication of the stream's overall quality. Parameters to be measured should be general data associated with the agencies' planning activities

   2. Abatement--place sample station location at the critical quality point below each major area of pollution sources. Measure those parameters denoted in the stream standards and any other parameters which are critical according to the waste outfall inventory.

The activities listed above do not consider a combination of a prevention and abatement objective. Data generated from an abatement surveillance network could be used for planning purposes, but the opposite is not true. Because of this, it may be desirable to establish two or three networks, each with a specific objective.

With the stream characterization complete, the sample station location and parameters of consequence have been determined. The next step is to determine the sampling frequency which yields the most information at the least cost. It must be noted at this point that some sampling frequencies are established by law and therefore cannot be changed without changes in the law. Hopefully, this would not be too difficult if it could be proven that another frequency is better.

Surveillance Network Simulation

In order to logically analyze the benefits associated with various levels of sampling frequency, some method for making comparisons must be developed. For this purpose, a relatively simple surveillance network simulation model has been established by Vanderholm (1972). This model has two basic parts. One is to be used in an analysis of the ability of a monitoring network to detect pollution events (abatement oriented), while the second part is designed to evaluate a network's ability to detect long-term trends (prevention oriented).

The mathematical models used in the surveillance network simulation were selected because of their characteristic of allowing a large number of trials to be made simulating various conditions using high speed computers. A field study of surveillance systems would require the installation of the necessary facilities or the observation of existing ones. To evaluate many systems under many conditions would be too costly and time consuming for a study of this nature. When using models, however, many systems under many conditions can be evaluated at a fraction of the cost and time involved with field studies. Models also require that much care be taken to insure the validity of the simulation for the situations under consideration. For this particular study, the models are developed to predict the performance of water quality surveillance networks for various water quality conditions. This implies that the study is concerned with modeling water quality surveillance systems, not water quality alone. The data obtained from the models is intended for use in design and evaluation of actual surveillance systems.

The first part of the surveillance network model was developed to study the effect of sampling location and frequency on the ability of a monitoring system to detect significant short-term quality variations or pollution events. The terms "pollution event" and "spill" are used synonomously in this study and refer to any short-term quality variation or extreme value from any cause which may indicate a stream standard violation. The model generates a series of these events at random times and locations on the stream reach under study. Downstream movement and dispersion of the pollutant is calculated. Various combinations of sampling times and locations are read into the program for testing, and if sampling and spill coincide at a certain point in time and space, detection of the spill is assumed. By testing the various sampling combinations with a large number of random spills, estimates of the sampling effectiveness can be made.

To study base level type data acquisition by grab sampling, both a statistical and model approach were used. In this second part of the surveillance network model, the objective is not to detect extremes but rather to obtain representative mean values. Statistical theory contains methods for estimating the number of samples necessary to predict a mean within a given range of the true mean for a known confidence level. This method requires only that some estimate of the variability of the parameter under consideration is available. By then specifying the allowable error, the number of samples necessary can be estimated. For the time period in question, number of samples is converted to a sampling frequency at the specified sampling stations.

The base level model was established in the following manner. The model generates a set of water quality data for a hypothetical parameter over a long time period. The characteristics of the generated data, such as mean and standard deviation are known. Various sampling schedules are tested by inputing them to the program and obtaining a set of observed data points from the generated data. An observed data point is that value occurring in the generated data at the point in time a sample is specified. The characteristics of the observed data can then be compared to the characteristics of the generated data. The model and the statistical presentation provide a means whereby the performance of a surveillance system in acquisition of base level type data can be evaluated.

The first part of the model which is concerned with pollution event detection will now be discussed. The effectiveness of a surveillance system in detecting a pollution event or stream quality standard violation is of primary importance for the regulation function. The state-of-the-art paper on grab sampling did not reveal any information or methods to quantify this characteristic for grab sampling, or even that any attempts had been made to determine the level of effectiveness. Since one of the objectives of this study is to evaluate grab sampling methods for regulation data needs, it was necessary to devise a method whereby a numerical estimate of detection levels could be made.

The method developed involves the use of a simple mathematical stream model. A program was written for the CDC6400 digital computer. A simplified flow diagram for the program is shown in Figure 5, while a complete listing of the program is found in the work by Vanderholm (1972). The basic program inputs are the geometric and hydraulic characteristics of the stream. For the initial analysis, a hypothetical stream was assumed with the following characteristics: average width, 200 feet; average depth, 1.5 feet; average velocity, 2 fps; average flow rate, 600 cfs; Manning "n" value, 0.025. These values are similar to those that can be expected on the lower reaches of the South Platte River in Colorado. Time of travel

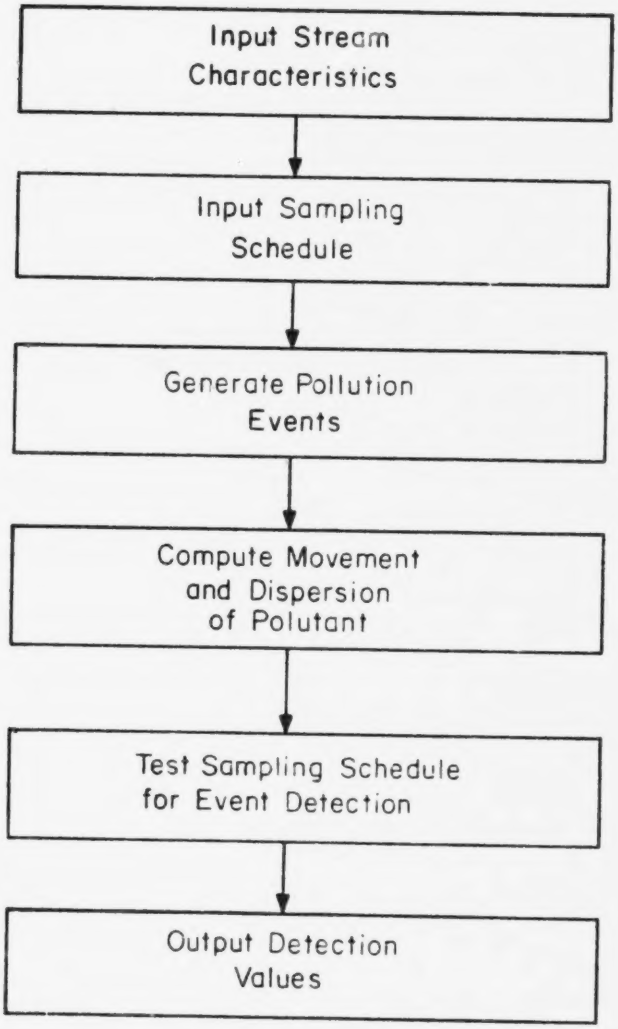
Input Stream Characteristics
Input Sampling Schedule
Generate Pollution Events
Compute Movement and Dispersion of Polutant
Test Sampling Schedule for Event Detection
Output Detection Values

Figure 5. Flow diagram for suveillance network simulation.

and dispersion of pollutants from a specific pollution event are calculated using these values. By specifying these values, the assumptions of uniform channel cross section and steady uniform flow are made. The length of the stream reach used was varied, depending upon the particular situation under study.

The arbitrary selection and use of a single set of values for stream characteristics is obviously not in accordance with an actual situation. However, sensitivity tests were performed on the model to check the effects of varying these values. These are described in the application section.

Location and time of pollution events are assumed to be completely random occurrences. A uniform random number generating function is used to select each of these parameters. For all of the analyses reported here, the location was a uniform random point anywhere along the entire reach under study. A base time period of 30 days was selected, while the time of pollution event occurrence was allowed to vary within the range of 0 to 30 days. Another pollution event characteristic considered was the length of time discharge occurs, or the spill duration. Since this may vary from an instantaneous spill to a continuous discharge over a long time period under actual conditions, the event time was studied as a independent variable, either specified or random within a specified range.

A method developed by Glover (1964) for the USGS was used to compute the longitudinal dispersion curves for pollutants during travel downstream. This method of solution requires the stream geometry and hydraulic characteristics described earlier.

Equation 1 is the form developed by Glover for calculating longitudinal dispersion.

$$S = \frac{Q_s}{BD} \; \frac{e^{-\left(\frac{x - \bar{v}t}{\sqrt{4K_x t}}\right)^2}}{\sqrt{4K_x t}} \quad . \; . \; . \; . \; . \; . \quad (1)$$

This is also the form used in the model where S is pollutant concentration in lb per 1000 cubic feet of water, Q_S is size of spill in lb, B is average stream width in feet, D is average stream depth in feet, x is distance from spill point to sampling point in feet, $\bar{v}$ is average stream velocity in feet per second, t is elapsed time since spill in seconds, and K_x is shear velocity in square feet per second. A detailed explanation on the use of this equation is found in the reference just cited.

The final dispersion curve for the sampling point along the stream reach in question is calculated by substituting values for t into Equation 1 and solving. The initial t value must be specified to occur just before the leading edge of the dispersion curve reaches the sampling point. By then incrementing t in finite steps until the significant portion of the pollutant has passed the sampling station, a curve such as shown in Figure 6 is obtained. Glover's formula calculates the longitudinal dispersion curve for a finite amount of conservative pollutant released instantaneously from a point source. A conservative pollutant can be described as essentially inert, such that no reactions occur which significantly add, remove, or change the form of the pollutant within the time period considered. Complete lateral and vertical mixing was assumed in all cases. If the distance from the spill to sampling point is very small, this assumption is not valid. In addition, this situation does not allow time for development of a dispersion curve from an instantaneous spill. The program contains provisions to compensate for this possibility.

The calculated dispersion curve is in terms of pollutant concentration versus time at a given location along the reach. The initial quantity of pollutant introduced must be specified. A value of 1000 pounds of pollutant was used in all cases except when sensitivity of the solution to this value was being checked. A background concentration of pollutant in the stream is also specified with the actual concentration curve being computed as the sum of background and pollution event concentrations. By then specifying a minimum detectable level for detection of a pollution event, a time period is defined during which a sample must be taken for the event to be detected. The term "minimum detectable level," as used here, does not refer to the actual concentration which can be detected by a given analysis technique. Rather, it refers to some concentration indicative of a pollution event due to its value being beyond the range of normal variation. The actual value of the concentration at any point in time is not important to the final desired solution, but is just a tool to arrive at the detection interval. A hypothetical pollutant that meets the requirements of this method is assumed throughout the study, but many common pollutants very nearly meet these requirements and the methods should be applicable to these.

In the case of a continuous discharge, no practical method of calculating longitudinal dispersion was found. For the present model setup, if a continuous discharge occurs, its duration is simply added to the detection interval for an instantaneous spill occurring at the same time and location, thereby increasing the detection interval by the duration of the spill. The discharge diluted by stream flow is still

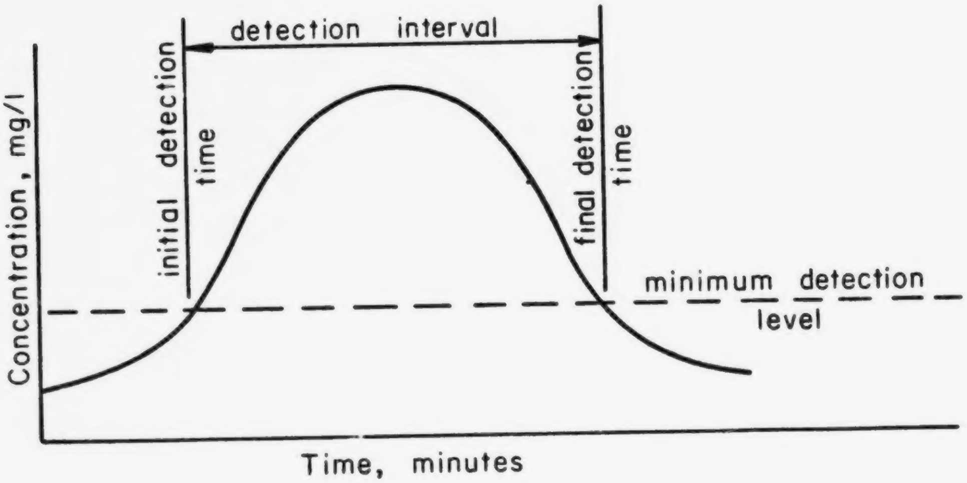

Figure 6. Example instantaneous spill dispersion curve.

assumed to be above the minimum detection concentration. This creates what approximates a square wave dispersion curve and as spill duration increases and the curve spreads out, the calculated dispersion become less influential on the detection interval length.

Sampling locations along a reach and sampling times at these locations are read into the program. Sampling times are specified within the same 0 to 30 day range as pollution event occurrence. Any sampling frequency from once to many times during this period may be selected. The model thus permits any combination of sampling location and frequency to be studied.

A brief explanation of the computation procedure is provided below. All necessary stream characteristics, sampling times and locations, and spill durations are read into the computer program. Uniform random numbers are generated to select the time and location of the pollution event. For each sampling location downstream from the spill location, a dispersion curve is calculated and the time interval for detection is determined. The given times of sampling at each station are tested against the calculated detection time interval and the computations are made as to whether or not detection occurs. Each pollution event is tested at each sampling location for all sampling times, if necessary. If detection occurs, no further locations and times are tested for that event, so that detection will not be counted more than once for the same event. When this is completed, a new pollution event is generated and the process repeated.

Presently, the program generates 50 events and outputs the number of events detected out of this total. This is repeated 20 times so the result is 20 sets of 50 events, or a total of 1000 random pollution events. The results are used to calculate the detection level for the specified sampling configuration and spill duration. The results from different combinations are compared and estimates made of quantitative values for detection.

Now the second part of the model concerning base level data will be discussed. For planning and other related purposes, it is necessary to have data that are representative of the ranges in stream quality that may occur in time and space. Short term variations such as diurnal are not considered here, but seasonal and annual variations as well as long-term trends are important. The state-of-the-art paper indicated that grab sampling was well suited to obtaining this type of data due to the less stringent sampling frequency requirements and to the wide range of parameters measurable by this method. In most instnaces, however, these observations were based on opinion and experience, rather than experimental evaluation. This phase of the study is designed to develop a method whereby the effectiveness of grab sampling in meeting data needs of this type can be evaluated.

Data of this type can probably be best presented in terms of some simple statistical parameters, such as means and standard deviations. This suggested that a theoretical statistical approach might be applicable. At the same time, it was felt that the evaluation could also be accomplished using simulation techniques. The end result was to use both so that the statistical theory was used as the basic evaluation procedure and a mathematical model developed for illustrative and comparative purposes.

A primary objective of employing statistics is to determine the sampling frequency necessary for obtaining representative base level data. As was the case throughout this study, the assumption is made that sufficient data is already available for designing the surveillance system. Using the known data, it was desired to establish a routine surveillance program which would adequately perform at a given level. Snedecor and Cochran (1967) present a simple method for answering the question, "How large a sample do I need?" This method was easily adapted to the problem at hand to answer the question, "What sampling frequency do I need?"

The first assumption is that a normally distributed population is being sampled. Since we are dealing with averages and since the "Central Limit Theorem" states that sample averages tend to become normal even if the original population is not, this assumption is easily justified. Next, an estimate is desired to be correct to within some limit, ±L. For 95 percent probability, there is a 95 percent chance that the observed mean $\bar{x}$ lies between the limits $u - 1.96\ \sigma/\ n$ and $u + 1.96\ \sigma/\ n$, where u is the mean, σ is the standard deviation and n is the number of observations. This gives the equation

$$1.96\sigma/\ n = L \quad . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \quad (2)$$

Solving for n and replacing 1.96 by 2 for simplicity gives

$$n = 4\sigma^2/L^2 \quad . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \quad (3)$$

Equation 3 has the form used in statistical comuptations for arriving at necessary sampling frequencies for given performance levels. Some estimate of the standard deviation, σ, for the data of concern must be available for the equation to be used. This completes the statistical approach, and the model approach will now be presented.

The model approach uses a simple mathematical model of a stream and surveillance system as the basic tool. Although actual water quality data for an existing stream could be used, the initial approach was to use hypothetical data. The advantage of this procedure was that the hypothetical data can be generated with known variations and trends. In addition, use of hypothetical data prevented the problem of trying to work with incomplete or inadequate data, which is often the case in real situations. The evaluation of the surveillance system will be accomplished by observing its effectiveness in detecting the known data characteristics.

A computer program has been written for development of the model (Vanderholm, 1972). The initial function of the program is to generate a set of long-term water quality data for a given point in space along a stream. The data includes known seasonal and annual variations, long-term trend variation, and random variation. The surveillance system characteristic of concern is the sampling frequency, which is handled as an independent variable. This is an input variable, and it can easily be changed to study various combinations. Again, a complete listing of the program can be found in Vanderholm (1972). The model does not consider the effect of sampling locations, since it deals with only one point in space. In actual design of a surveillance system, it is anticipated that sampling station locations will be established on the basis of known river and pollution source characteristics. After these locations are established, it will be necessary to study the variability of the desired quality parameters to arrive at a sampling frequency adequate to obtain the representative data.

A bried description of the computation procedure by this program is as follows. A hypothetical historical data set for a desired parameter is generated for a sampling location. For example, this could consist of ten years of weekly observations of a particular parameter. The known data characteristics could include annual means, a cyclic seasonal variation and a random normal error term with a specified standard deviation. A proposed sampling schedule is read into the program for evaluation. Data values and sampling schedule have time subscripts so that a sample taken at any time will fall on a single data value, or between two values. An observed data value is obtained either by interpolation or by direct reading, if sampling and data time correspond. These observed values are retained and the characteristics of the hypothetical data. By varying sampling frequency, it is possible to estimate a frequency which will result in reasonably representative data.

Data obtained from this model is compared to that predicted by the previously described statistical approach. While it is realized that many trials should be made to obtain values that are statistically valid, it is felt that the model data serves as a useful illustration of what may be happening in an actual situation.

The above described surveillance network simulation models permit a quantitative evaluation of a surveillance network design. Optimum as used here refers to that design which best meets an agency's needs when the financial and manpower constraints under which the agency must operate are considered.

It is not proposed that every state go through the modeling phase of the design procedure, although the modeling is simple and mainly requires only access to a computer. The analysis to be presented under the application section of this report will illustrate the results of the model and this information in itself will provide a state agency with a much better feel for the relationships that exist between effectiveness and frequency. This information, combined with a stream's characterization, will greatly improve a routine sampling network.

Up to this point in the design procedure, sampling location, parameters to be measured, and sampling frequency have been analyzed. Thr fourth and last aspect of the grab sample design procedure is a cost analysis of the various designs.

Cost Analysis

The primary reason to establish a cost analysis is to determine the trade-offs between performance and cost so the routine network manager can obtain the most information with his budget. The performance evaluation has been developed previously; therefore, this discussion will outline the accumulation of cost information and relate this to performance.

The determination of costs associated with grab sampling involves three major categories. These are collection, analysis, and handling costs. Costs will be determined on a per sample basis. Using costs on a per sample basis will permit easy analysis of alternative sampling frequencies, number of samples, etc.

Obtaining costs on grab sampling will involve a determination of actual expenses associated with collection, analysis, and data handling. Collection costs include salaries, transportation (both of collectors and shipping of samples to the laboratory), and field analysis equipment amortization. Laboratory analysis costs will include salaries of laboratory personnel, laboratory equipment costs, and purchases of expendable chemical reagents. Data handling costs can vary widely, depending upon the level of data handling; but in general, the costs will include salaries and expenses related to automatic (computer) storage and retrieval. The sum of the above costs should yield the total cost associated with an agency's grab sampling data acquisition efforts. This total can then be divided by the total number of samples collected within the time span considered in calculating the costs. This then gives a cost per sample which can serve to relate cost to effectiveness.

The effectiveness versus frequency relationships developed in the previous sub-section provide a means of relating the number of samples to some level of effectiveness. Now the above cost information provides a relationship between number of samples and cost. Therefore, by using the number of samples as a common factor, the very important relationship between cost and effectiveness can be developed. This will be illustrated clearly in the application section.

Costs for automatic monitoring and remote sensing are developed in their respective state-of-the-art papers. These costs will be fairly uniform across the country, and consequently, they were not considered dependent upon the state's location. This is not true for grab sampling costs since they are dependent upon prevailing wage rates, size of state, etc. This is the reason for the above discussion of grab sampling cost determination.

The comparisons of cost-effectiveness of grab sampling versus automatic monitoring or remote sensing are difficult to make because of the different types of data acquired. For this reason, the decisions relative to these techniques must be based more on the goals of the agency relative to types of data supplied and to the relative costs involved. These aspects of the techniques will be discussed in the application section.

Sensitivity Analysis

As was briefly mentioned in the above section, an analysis of the performance versus cost is needed to provide the necessary information to a surveillance network manager so that he can make rational decisions concerning its design. This will be accomplished by evaluating two levels of desing alternatives: 1) alternate levels of grab sampling; and 2) alternate data acquisition techniques (automatic monitoring and remote sensing). A third alternative with respect to data collection would be to consider different pollution control strategies.

The levels of grab sampling will be evaluated by presenting various degrees of effectiveness versus the costs involved. The water quality manager can weigh this information against other factors involved and then make his decision with respect to grab sampling. By presenting various levels of effectiveness versus cost, the decision maker can visualize how sensitive the data acquisition system is to changes in cost, manpower, etc.

The alternate data acquisition techniques will be evaluated as to their ability to replace a part of all of the grab sampling network. Automatic monitoring is geared almost exclusively to supplying an abatement or enforcement type of data. Thus, automatic monitoring will be evaluated with respect to its ability to replace the abatement part of a grab sampling network.

Evaluation of remote sensing as an alternate data acquisition technique will involve a general comparison between a comprehensive space coverage, a severe limitation on parameters, and a relatively high cost of operation. Relating this to grab sampling and automatic monitoring will be accomplished through a specific discussion of its merits, cost, advantages, and disadvantages in the field of routine water quality monitoring.

SECTION VIII

APPLICATION OF DESIGN PROCEDURE TO COLORADO

In this section, the procedure developed earlier in the report will be applied to the State of Colorado. The application will be performed using the data available; therefore, some aspects of the procedure application will be weak due to a lack of available data. This is especially true with respect to waste outfall inventories. With the current concern over permit systems, however, this data should generally be available to water management agencies in the near future. Also, the federal requirement for completed regional plans before waste treatment construction grants are funded is contributing to the information needed to apply the surveillance design procedure. These regional plans require information on waste outfall location, flow, and character. This information will be necessary in determining which parameters are to be measured.

Application Area and Conditions

Prior to the design of any system to collect data, the entity to be described by the data must be understood. For a water quality surveillance system, this includes an understanding of the effects of physical, economic, and legal aspects upon water quality. This is especially true in Colorado, where there are wide variations in climate, topography, and population density. Each of these variations has a large effect on Colorado's water quantity and quality.

Physical Conditions

Colorado's topographical uniqueness is very evident when one observes a relief map. The eastern half of the state consists of flat high plains and broad rolling prairies, while the western half consists of alpine terrain. The state is bisected by the Western Continental Divide of the Rocky Mountains and contains 53 mountains higher than 14,000 feet. With an average altitude of 6,800 feet, Colorado is the highest state in the Union.

In total area, Colorado is the eighth largest of the 50 states, with 104,247 square miles. The United States Government owns over one-third of the land area and uses it for National Forests, National Parks and Monuments, military

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reservations and federal installations. As for neighbors, Colorado is bounded on the south by New Mexico and Oklahoma; on the east by Kansas and Nebraska; on the north by Nebraska and Wyoming; and on the west by Utah.

Rainfall in Colorado is light, and consequently water is a most carefully guarded resource. The eastern plains have an annual precipitation of from 6 to 18 inches, with the Denver metropolitan area receiving an annual average of from 12 to 14 inches. In the mountains, annual precipitation varies from 18 to 26 inches, with a large part of this in snowpack. Based on the above precipitation averages, only pasture of limited value can be grown without irrigation.

Due to its high elevation, Colorado contains the headwaters of four major river basins. These are the Colorado, Rio Grande, Arkansas, and Platte Rivers. The rivers and streams carry water out of Colorado in all directions into adjoining states with no useable streams bringing water into the state. Colorado, therefore, depends on water generated within its boundaries.

The population of Colorado increased 25.8 percent between 1960 and 1970 to a current (1970) total of 2,207,259. Of this total, approximately 74 percent live in a narrow band along the eastern edge of the Rocky Mountains from Fort Collins to Pueblo. By the year 2000, the population within this "Front Range" area is expected to be 3.2 million--a doubling of population in 30 years. The Front Range is currently supplied with clear water as it flows down from the mountains.

Economic Conditions

Colorado's economy has been based on its natural resources. Mining, and agriculture based on irrigation, were the original economic endeavors, but recently the excellent environment (crisp, dry air; pure mountain streams; etc.) has lured many recreation minded and environmentally conscious people and industries into the state. Also, many government installations are located in the state. This has led to rapid growth as illustrated in the above population figures. More water is being demanded to satisfy the growing needs as more pressure is being exerted upon environment.

As a result of the large growth on the Front Range, the Colorado-Big Thompson project was developed and is currently capable of transferring 300,000 acre-feet per year from the Colorado River to the South Platte River Basin. The Frying Pan-Arkansas project will also import some 67,000 acre-feet per year into the Arkansas River Basin (Colorado Water Pollution Control Commission, 1967).

Legal Conditions

States in the eastern part of the United States use the Riparian Doctrine with respect to water. Since this doctrine is dependent upon adequate stream flow, it does not work in semi-arid or arid regions. For this reason, Colorado uses the doctrine of Prior Appropriation. Under Colorado law: 1) water in its natural course is the property of the public, and is not subject to private ownership; 2) a vested right to use the water may be acquired by appropriation and application to nebeficial use; 3) the person first in time to use the water is first in right; and 4) beneficial use is the basis, the measure, and the limit of the right (Colorado Water Pollution Control Commission, 1967).

There are certain preferences in use of water under Prior Appropriation as stated in the Colorado Constitution. It states in Section 6, Article XVI, that:

> "The right to divert the unappropriated waters of any natural stream to beneficial use shall never be denied. Priority of appropriation shall give the better right as between those using the water for the same purpose; but when the waters of any natural stream are not sufficient for the service of all those desiring the use of the same, those using the water for domestic purposes shall have the preference over those claiming for any other purpose and those using the water for agricultural purposes shall have preference over those using the same for manufacturing purposes."

From the above, it can be seen that an individual does not actually own the water, but he has the right to take from the source of supply, sufficient water to meet his daily needs. "Sufficient" depends upon the limit of his decree.

Because of the prior appropriation doctrine, diversions along the foothills take water from the streams and canals deliver it to the users. This leaves the streams with little or no flow until the return flow from agriculture, municipalities, and industry begin to enter the streams. Therefore, streams, past the points of use, today run continuous where, in early history, they were intermittent. As a consequence of prior appropriation, the streams consist primarily of return flows or wastewater--an important point to remember when developing a strategy to control water quality.

In summary, physically Colorado has many variations and constrasts, and legally it allows water to be removed from the streams and put to beneficial uses. These facts are extremely important when considering a water quality management program for Colorado. They also have a very large influence on the data acquisition system to be used in managing the water quality.

Stream Characterizations

The stream characterizations are performed by river basin with the major main stems being analyzed in more detail than their tributaries or other smaller streams. For the main stems, water quality data available from the Water Pollution Control Division (WPCD) of the Colorado Department of Health is used to develop graphical representations of the river's quality over the total length. For the tributaries, the WPCD data is put into tables. Many of the smaller rivers and tributaries have too few data points to warrant graphical representation. Since the WPCD does not currently have a waste outfall inventory for the state, this information will not be included in the analysis.

Biochemical oxygen demand (BOD), dissolved oxygen (DO), pH, total dissolved solids (TDS), and flow are the parameters used in this particular characterization. This is not to say that these are the only ones which should be used, but they were chosen for this particular study. The WPCD has been collecting data since 1968, and the means and standard deviations used in the characterizations are obtained from the three years, 1968-1970. The stream characterization details are contained in Appendix D.

In summary, the characterizations indicate that the South Platte River is the major problem area of the state. Here the industrial, municipal, and agricultural uses of the water cause the stream to be high in biochemical oxygen demand (BOD), low in dissolved oxygen (DO), and high in total dissolved solids (TDS). Also, since the majority of the population of the state lives in this basin, it also has high pollution potential as witnessed by the variation observed in the data presented in Appendix D.

The Arkansas River has general quality problems near the population centers, but its main problem is salinity as it leaves the state. This shows very clearly in the graphs in Appendix D. The Colorado River and Rio Grande River also have salinity as their major problems as the urban development is minor in their basins. Acid mine drainage and natural geologic conditions in addition to agriculture contribute to the salinity problems.

The data contained in Appendix D will be used in the following analysis. When this data is used, references to it will be noted.

State Agency Strategy

Colorado's Water Pollution Control Division's (WPCD) strategy was determined by having several of the Division's staff complete the form in Figure 3. A completed form is shown in Figure 7. The completed form shows totals of 206, 260, and 254 for prevention, abatement, and program control, respectively. This results in percentages of 0.29, 0.36, and 0.35 for each of the broad objectives. Other staff members had percentages of 0.30, 0.38, and 0.32; and 0.30, 0.36, and 0.34 for each of the objectives. This indicates general agreement of the relative levels of effort. Point totals for the total chart were 489, 720, and 851 for each of the respondents out of a possible 1,080. This indicates the view of the program available to the respondent since the lower figure was supplied by an engineer in the program while the top figure was supplied by the Division's director. The important fact here, however, is the general agreement of relative levels of effort among the Division's personnel. It is these relative levels that determine the state agency strategy. An analysis of budget allocations among the various portions of the program should reveal similar results.

The numbers in Figure 7 and the percentages presented earlier indicate that the Colorado Water Pollution Control Division (WPCD), in general, emphasizes abatement over prevention. In the area of prevention, Figure 7 indicates medium activity in planning, low to no activity in research, and high activity in aid programs. Therefore, within prevention, aid programs receive the largest amount of effort. Referring back to Figure 2, the data needs of aid programs are nil, which implies that water quality data needed for prevention will primarily be that associated with planning. In the past, the WPCD has had very little planning activities due to its limited size; but now that the federal government requires regional plans with each sewage treatment plant construction grant application, the WPCD can be expected to increase its planning efforts. This in turn will place a data demand upon the surveillance network. If the WPCD were not currently getting into planning, it could be said that the WPCD need not collect data for prevention purposes since it was devoting its efforts to abatement, which would be the strategy of the agency. However, since planning is being emphasized, the surveillance network must reflect its need of data.

	Activity Level				
	High	Med	Low	None	Points
Prevention					
A. Planning	30	20	10	0	
- Program Planning		x			20
- Project Planning		x			20
- Planning Coordination		x			20
- Contingency Planning			x		10
B. Research	24	16	8	0	
- Develop Research Needs				x	0
- Approve Research Proposals			x		8
- Evaluate Progress of Sponsored Research			x		8
- Research Coordination				x	0
- Conduct In-House Research				x	0
C. Aid Programs	60	40	20	0	
- Grant and Loan Administration	x				60
- Coordination of Grants and Loans	x				60
Total for Prevention					206
Abatement					
A. Technical Assistance	20	13	7	0	
- Approve WTP Plans and Specifications	x				20
- Inspect New Construction			x		7
- Recommend WRP Site Approval	x				20
- Train WTP operators		x			13
- Inspect WTP Operations		x			13
- Recommend Abatement Steps for Polluters	x				20
B. Regulation	20	13	7	0	
- Issue Permits				x	0
- Approve WTP Sites	x				20
- Develop Abatement Schedules for Polluters	x				20
- Review Stream Standards	x				20
- Recommend Changes in Regulations	x				20
- Initiate Further Internal Action for Persistent Polluters	x				20

Figure 7. Pollution control strategy determination for Colorado as completed by a WPCD staff member.

	Activity Level				
	High	Med	Low	None	Points
c. Legal Enforcement	20	13	7	0	
- Issue Cease and Desist Orders	x				20
- Conduct Hearings	x				20
- Prepare Briefs for Court			x		7
- Initiate Court Action		x			13
- Prepare Laws and Regulations			x		7
- Levy and Collect Fines				x	0
Total for Abatement					260
Program Control					
A. Information Collection	40	27	13	0	
- Surveillance Network		x			27
- Field Investigations	x				40
- Other Sources		x			27
B. Information Processing	20	13	7	0	
- Screen		x			13
- Verify		x			13
- Interpret		x			13
- Index			x		7
- Store			x		7
- Retrieve			x		7
C. Action Initiation	30	20	10	0	
- Action Need Reports	x				30
- Inventory and Data Summaries		x			20
- Special Reports	x				30
- Publicity		x			20
Total for Program Control					254

Figure 7. (Continued)

As noted in Section V, planning requires large amounts of data from many sources. The major data requirement that planning places upon the routine monitoring program is associated with base level trends. The other types of water quality data are collected through special inventories, surveys or a permit system. In addition to water quality data, the planning function must have data on population trends, economic conditions, legal and institutional arrangements, etc.

The creation of a good historical record or the establishment of base level water quality conditions does not require the data acquisition sophistication that enforcement and regulation require. The data need only indicate the means and standard deviations, not the extremes in variation or the relation of parameter extremes to waste outfalls required for regulation. Because of this the data need not be as precise or as thorough as specific data for abatement purposes. It can simply be a representation of the summed effect of all pollution loads on the stream.

To establish a water quality base level, the designer of a surveillance system must consider parameters, sampling station locations, and sampling frequencies. Each of these will be discussed in detail with respect to prevention and then an application to Colorado will illustrate the utilization of the guidelines that are presented.

Looking at abatement in Figure 7, it is noted that technical assistance and regulation both command high levels of activity while legal assistance has a medium activity level. This indicates that the WPCD is generally successful in the use of "conference, conciliation, and persuasion" in abating pollution and, therefore, the legal activities reflect a lower level of effort. The WPCD operates under the Colorado Water Pollution Control Act in which paragraph 66-28-10 states:

> "Whenever the division of administration or county health department shall have cause to believe that any person is engaging or threatening to engage in any act or practice which results in the violation of a waste discharge or water quality standard, or which results in the violation of any other rule or order of the commission, the division or county health department shall so inform the commission and promptly cause an investigation thereof to be made and, if the division or county health department shall find, after such investigation, that a violation of any such waste discharge or water qualtiy standard or other order exists, it shall by conference, conciliation, and

> persuation, endeavor to eliminate the alleged violation."

It is form this section of the law that the agency derives its enforcement tool. Abating pollution using "conference, conciliation, and persuasion" as the enforcement tool requires large amounts of time and effort in regulation, especially in the development of abatement schedules, and in technical assistance as related to persuading a polluter to stop polluting. A perfect example of this has been the situation in Greeley, Colorado, which occurred during 1971. The city was violating the regulations and the division engineers had to spend many months persuading Greeley officials to remedy the problem. This required the engineers to develop a report on the technical aspects of the problem and possible technical solutions.

The question must be asked, if the agency were to devote more effort to legal enforcement, could activity levels in technical assistance and regulation be reduced. If this is possible, the data needs of the agency will necessarily reflect the change in effort. Under current law, however, under which this analysis is being performed, the emphasis is on "conference, conciliation, and persuasion" and, consequently, the WPCD must concentrate its abatement efforts in regulation and technical assistance. Therefore, the data collected for abatement must support the regulation and technical assistance efforts. Hager (1970) puts particular emphasis upon the fact that regulation and enforcement are dependent upon surveillance.

Elaborating further on data needs for regulation and enforcement, it should be noted that the surveillance system must yield data that verifies if stream standards are being met. As noted earlier in the grab sampling state-of-the-art papers, Velz (1950) expanded upon the fact that in order to accurately analyze data for stream standard violations, the data must have a statistical basis upon which conclusions can be drawn. Otherwise, there is little basis for enforcement action.

The legal enforcement of stream standards revolves around the parameters and conditions enunciated in the law. For the Colorado WPCD, there needs to be data available to insure compliance with the criteria on coliform, dissolved oxygen, pH, taste and odor, dissolved solids, turbidity, temperature, and toxic materials among others. The data should statistically state whether criteria are being satisfied for these parameters as well as any others that may be crucial to that particular stream.

If it is noted that the criteria are not being met, the WPCD uses the data to "persuade" the violator to clean up. In this capacity, the data must be utilized to develop recommendations for eliminating the problem (technical assistance). As Bramer (1970) has noted, the need for data upon which to base treatment facility recommendations becomes more acute as the receiving streams become more sensitive to waste loads due to flow and/or to water uses which require more consistently high water quality. Therefore, the routine monitoring should provide in-stream water quality data which will serve to determine the variability of the rivers flow and quality, and this should be tempered with the uses of the water. The development of a relationship between stream criteria and size and variability of a stream is crucial to determining realistic alternatives for violators.

If "persuasion" is not successful, the data must be able to stand up in court. Unless the data is obtained from an extremely well designed routine surveillance network or by well planned special studies, there is little chance of the data being able to withstand the courtroom procedures. In this light then, the data must be accurate and precise.

As has been alluded to above and noted in the state-of-the-art paper on grab sampling, the exact nature of the data needed by a water quality management agency for any particular stream, will depend greatly upon the character of the stream. This is especially true in Colorado where some mountain streams have acid mine drainage to contend with while others have quality problems associated with recreation while others have problems related to natural pollution. On the plains, some streams pass through large urban areas while others are used entirely for irrigation purposes. Clearly there has to be careful analysis and interpretation of water quality data obtained from Colorado streams to insure appropriate use of the data.

In summary, the Colorado WPCD, under current enforcement procedures, needs specific data for abatement purposes and historic or trend data for prevention. The routine surveillance network supplies some of the specific data and all of the treand data currently used. Special surveys and inventories supply much of the specific data required.

Before leaving the discussion of state agency strategy, a few comments will be made on the program control point totals of the respondents. All respondents indicated a high level of activity in information collection, low in information processing, and low to medium in action initiation. This assessment could probably reflect the activity levels of most agencies in the United States. There needs to be more balance between data collection, data processing and action generation based on the data. Colorado has taken one step in this direction by making use of the STORET (a national water quality data storage and retrieval system sponsored by the

Environmental Protection Agency) system, but because of the agency's limited size, no one person is in charge of data manipulation. This prevents complete utlization of the data because there is no complete analysis of the data. As planning activities within the agency increase, there will necessarily be increased interest in and use of the surveillance data.

Sampling Station Locations

As noted in the State-of-the-Art Section on grab sampling, location of sampling stations can be influenced by many factors and by as many opinions. Some of these factors are present and potential pollution sources, water usage, physical stream characteristics, sampling convenience, and response to public clamor. Once the stations have been located and data has been collected for a number of years, another factor enters the picture as far as a re-evaluation of the surveillance system--loss of continuity if a station is moved or discontinued. Considering all these factors, sampling station location must be a compromise--no one point will serve or satisfy all factors involved.

The first step in determining sampling station location is to determine the factors involved for the existing situation. For Colorado, and as will be the case for most states, the design of a surveillance system for the state is basically a re-evaluation of the existing system. This results from the fact that data from the existing system is used to design the new system. This immediately presents problems with determining sampling location since the data available is dependent upon previous sampling locations. If only the routine surveillance data is used, it will be difficult to justify moving a station from its present location since nothing is known of the river until the next station. This implies that a more intensive survey of the stream's water quality is needed if adequate justification is to be developed for moving, discontinuing, or creating new sampling stations. Since Colorado does not currently have the information available to develop the justifications, no attempt will be made to analyze station location with the exception of the Cache la Poudre River. The WPCD is currently developing the necessary reports and one has been completed for the Cache la Poudre. This tributary of the South Platte will be analyzed to illustrate the suggested procedure for determining station location. Since the data is not available for the remainder of the state, the station locations will be taken as given and the frequency will be analyzed and determined.

Cache La Poudre River Sampling Station Location Analysis

The comprehensive Cache La Poudre survey was performed to determine existing water quality, to identify sources of pollution, and to analyze effects of pollution on the Poudre's quality. The Poudre was sampled for its entire length of 90 miles with a total of 110 sampling points used. The report does not state such, but apparently only one grab sample was taken at each point. The samples were taken between May 5 and June 12, 1970. A followup survey was performed from September 8 through October 13, 1970. The survey during May and June occurred during the high water flow and consequently, there was a large dilution factor which reduces the effect of municipal and industrial effluents. Even so, there were violations of stream standards at several points.

The survey during September and October was performed during the low flow period of the year and consequently, its results would show the more critical areas. Because of this, the results of the Fall survey will be used in this analysis. Also, since the water in the mountains is of very good quality, there is little need to routinely sample there. Therefore, the station locations will be considered only for the lower stretches of the Poudre.

The results of the Fall survey are summarized in Figure 8 using the water quality index developed by Brown and others (1970). Also noted in the figure are the existing sampling stations. The station at point 84 was established as a result of the stream survey. The chart in Figure 8 presents a very good picture of the water quality situation in the Poudre River. A corresponding flow curve would be extremely valuable, but none is available. The chart, however, does point out the fact that the sampling station above Fort Collins is monitoring water of very high quality, while the other two are monitoring water quality problem areas. The upper station was established to monitor the quality of water supplies to Greeley and Fort Collins. Since the WPCD is concerned primarily with controlling water pollution, the question must be asked whether the WPCD can afford to monitor water supply intakes. Should the water treatment plant do this, and could they not do it better? How much information can one sample per month supply to the treatment plant operator? Based on these facts, it would appear justified to discontinue the sampling station above Fort Collins and leave the other two. Also, according to the chart, there does not appear to be a need for any other stations.

The comprehensive survey has indicated the problem areas and the routine sampling stations have been located accordingly. An analysis similar to this needs to be performed whenever sampling stations are to be located or moved. Realistically,

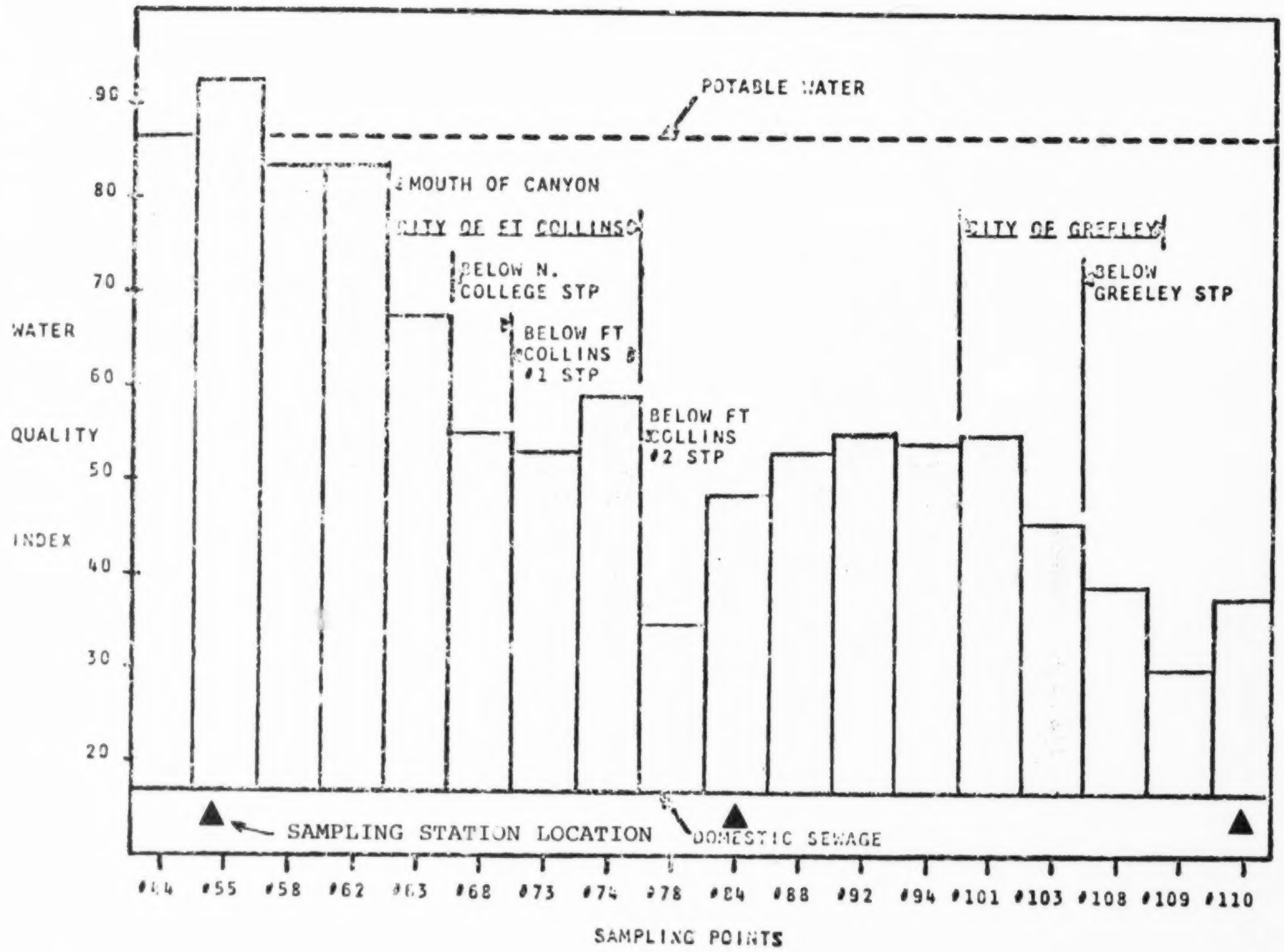

Figure 8. Cache La Poudre River - September, 1970. (Courtesy of the WPCD, Misbach, 1972)

the location of routine sampling stations should be an objective of every stream survey along with waste outfall inventories, water quality determination, etc.

Grab Sampling Frequency

As with sampling station location, there are many factors which affect sampling frequency. Some of these are pollution potential, water use, hydrological conditions, cyclic pollution patterns, and available resources for sample collection and analysis. The last factor mentioned is apparently the most limiting with respect to increasing sampling frequency. This is definitely the case in Colorado. It is, however, very difficult to justify increased sampling frequencies unless some increase level of effectiveness can be associated with the increased frequency. Effectiveness, as used in this report, will be a measure of how well the sampling data represents the true water quality conditions in the stream.

Colorado established a surveillance system in 1967, but did not actually begin routine surveillance until 1968. There were 77 stations which were sampled monthly. This network and sampling frequency were in response to the Pollution Control Act as amended. The state established stream standards with guidance from federal levels, but the surveillance was established with little local experience or federal help. Consequently, one sample a month was chosen largely because at the time no information was available to indicate that it should be otherwise.

Although one sample per month does not lend itself to a very active enforcement program, it has established some valuable trend data. It is this trend data that was used in the characterization of Colorado's streams contained in Appendix D. An analysis of the stream characterizations indicates very clearly that some Colorado waters are likely to have their stream standards violated more often than others. A mean near the stream standard and a large standard deviation foretells that violations are prone to happen at the point in question. Likewise, a mean which is not near the stream standard and a small standard deviation indicates that the chance of a violation is quite small. Therefore, if one is permitted to predict the future from the past, it can be said that certain stations are very crucial to insuring no stream standard violations occur while others are not. This is not to imply, however, that some stations are not to be sampled; it only indicates that there should be differences in sampling frequency to match differences in quality variations and possible stream standard violations.

Past water quality trends are not the only aspect to be considered. There is a greater possibility of violations in heavily populated areas than in areas not heavily populated. This factor may indicate a need for a larger sampling frequency in urban areas than in rural or mountain areas. In a mountian area it may be necessary to sample some stations more often than others due to mine tailings or in rural areas due to feedlots or irrigation return flows.

Secondary and Primary Sampling Networks

The above discussion indicates a need for several sampling frequencies in a surveillance network, depending upon the situation. Given a number of sampling stations, it would be possible to have a different frequency for every station, but this is not very practical. Also, since no one sampling frequency is adequate for all stations, there must be some compromise. For Colorado, the suggested compromise is two sampling frequencies. The high sampling frequency will be on a primary network, while the low frequency will be on a secondary network. This recommendation is made because Colorado has a highly urbanized front range, where its greatest pollution potential exists, while the remainder of the state is rural and mountainous where there is less pollution potential. This is not to say that all primary stations will be in the urban areas and all secondary stations will be in the rural areas, but in general, the primary stations will be at critical points while the secondary stations will be in less critical areas. This will permit the acquisition of more data in areas of high variation or high probability of stream standard violation, while reducing the effort devoted to stations which are fairly constant. There is no loss of information on the secondary stations since they are fairly constant, and the money and manpower devoted to them can better reflect their importance to the overall program. Likewise, with the primary stations, where more effort is being devoted to surveillance.

Another way to look at the primary-secondary concept is from the objectives of the state agency. As disucssed earlier in the report, a water quality management agency has two broad objectives--prevention and abatement. As illustrated in Figure 1, prevention, in general, requires trend data while abatement, in general, requires specific data. In this context then, the primary and secondary networks both supply trend data for the entire state while the primary network supplies specific data at the points where abatement is needed. Hence, the surveillance network is geared to the data needs of the agency.

For Colorado, the designation of sampling stations as either primary or secondary was accomplished as follows. Those stations which had high variability and were located in a highly populated area were given primary classification. The stations which had high variability with small population or low variability with high pollution potential were considered on an individual basis. Those stations which had small variation and little pollution potential automatically were put into the secondary classification.

In performing the evaluation, the figures and tables of Appendix D were used to determine variability. Due to a lack of information on waste outfalls, the pollution potential was determined from consideration of population density and industrial and agricultural activity.

For the Arkansas River, Figures D-1, D-2, D-3, and D-4 of Appendix D illustrate graphically the variation in water quality. All parameters are fairly constant until the river passes Pueblo. For the Nepesta and La Jurta stations the biochemical oxygen demand (BOD) is quite high and, as shown in Figure D-3, the variability is large. As the river nears the state line, the total dissolved solids (TDS) reaches its maximum and is quite variable. Because of the high pollution potential from Pueblo and the variability at Nepesta, La Junta, and Holly, these stations are designated as primary stations with the remainder being secondary stations.

The tributary to the Arkansas which appears to have serious problems is Fountain Creek. It passes through Colorado Springs and enters the Arkansas at Pueblo. Its flow is quite small to be serving such a high population, but its stream standards reflect the fact that it would be very difficult to maintain a high quality water in the creek. Due to this extremely high pollution potential, the station below Colorado Springs should be a primary station with the other two being secondary. Due to the fact that none of the other tributaries appears to be near violating its stream standards, and to low pollution potential, the remainder of the stations in the Arkansas River Rivsin should be secondary.

For the Colorado River, Figure D-5 indicates that everything except the flow remains fairly constant until near the state line, where the BOD rises. Figures D-6 and D-7 indicate that there is some variability in dissolved oxygen (DO) and BOD, especially at Dotsero and near the state line. At Dotsero, the standard deviation curve for DO is well below the stream standard, indicating violations may occur often. Population density and industrial and agricultural activity on the upper Colorado main stem are most critical in the Grand Valley.

Much of the pollution probelm in the Colorado is due to TDS buildup as the water passes over geologic formations which contribute a heavy salt load. In Grand Valley, irrigation return flows contribute to the salt load. From this analysis, the station at Dotsero and either the station at Loma or the Environmental Protection Agency (EPA) station at the state line should be primary, with the rest being secondary.

For the tributaries to the Colorado River, there do not appear to be any major problems besides the TDS situation. Table D-4 indicates that the major points of TDS problems are when the tributaries with large flows enter the Colorado or other tributaries. The Uncompahgre, a tributary to the Colorado, has high TDS at Delta. The Gunnison also has high TDS and a very high flow as it enters the Colorado. Other tributaries with high flows are the Eagle and Roaring Fork Rivers. Both of these also have a small probability of DO and pH problems. For these reasons, the four stations mentioned should be primary stations, while the remainder of the stations in the Colorado River Basin in Colorado should be secondary.

Figures D-9, D-10, D-11, and D-12 illustrate the water quality variation of the main stem of the South Platte River. It is this basin which also has the largest concentration of population density and industrial and agricultural activity in Colorado. Denver is generally situated between Littleton and Henderson, and as Figure D-9 illustrates it is between these two points that the BOD is the largest and DO is the lowest. Between Henderson and Kersey, the St. Vrain, Thompson, and Cache la Poudre Rivers all enter the main stem, so recovery from Denver is not as fast as possible. Beyond Kersey, the river recovers and remains fairly stable to the state line. Because of the variation and pollution potential, the stations at Henderson and Kersey should be primary and the stations at Littleton and Julesburg should be primary to determine quality of inflow to Denver Metro area and the quality of water leaving the state, respectively. Also, the TDS standard at Julesburg may be violated, but since flow measurements are not taken, it cannot be determined. It will be recommended later that flow measurements be obtained so that the TDS stream standard can be checked.

By observing the variations of data in Table D-6 and considering the pollution potential, the primary tributary stations were determined. These are the stations at the mouths of the Cache la Poudre River, Big Thompson River, and Clear Creek. Also, primary stations are those on the St. Vrain below Longmont, Boulder Creek at the Weld-Boulder county line, the remaining two stations on Clear Creek, Bear Creek, and a new station on Cherry Creek. This network of primary stations will supply data on the major streams in the Denver area and on those major tributaries entering the South Platte north of Denver.

Tables D-7 through D-13 of Appendix D contain the stream characterization data for the remaining streams in Colorado. Generally, the pollution potential in the areas of these remaining streams is low, as is the water quality variation. TDS is a problem at some stations, but there is no way to tell how near it is to violating the stream standards since no flow measurements are made. For these remaining stations, therefore, a secondary designation will be applied.

Sampling Frequency versus Effectiveness

In order to determine the primary and secondary sampling frequencies, there must be some relationship between sampling frequency and effectiveness. As mentioned in the previous section under "Stream Simulation," Vanderholm (1972) has developed the needed relationship. It should be pointed out, however, that the predictions made in the generation of relationships should not be taken as absolute, but rather as relative comparisons for various sampling combinations.

In developing these relationships, Vanderholm used two approaches. One set of relationships will determine the ability of a monitoring network to detect spills, or in general, to detect rapid changes in water quality. The other set will determine the ability of a station to detect trends. These two analyses roughly follow the breakdown of the network into primary and secondary stations.

In the area of spill detection, relationships have been developed to illustrate the effect of number of samples, number of sampling stations, and spill duration on the sampling frequency. In trend analysis, relationships have been developed to illustrate number of samples versus the error between sample and true value which can be tolerated. These relationships, with cost data, will be used to relate cost to effectiveness.

The relationship between number of samples and pollution event detection was determined by establishing a stream reach length of 100 miles in the stream simulation model and establishing a sampling point at the downstream end of the reach. Spill location was completely random along the entire reach and time of occurrence random in the range 0 to

30 days. A random spill duration from 0 to 3 days was used. Sampling times were uniformly spaced over the 30 day period and the number of samples varied from 2 to 30. The results of this trial are shown in Table 2. The total number of samples can also be described as the total number of chances to detect each pollution event. The data indicates that the detection probability is proportioned to the number of samples taken. Figure 9 illustrates this graphically. The relationship is not linear. Since a random spill duration is used, a certain number of short duration spills will remain undetected until the time interval between samples is smaller than the detection interval of the smallest spills. This accounts for the decreasing change in detection with change in sampling frequency. To obtain a detection level of 100 percent under these conditions would require a very high sampling frequency which would probably not be feasible.

Still considering spill detection, a relationship is developed between the number of sampling stations and sampling frequency while holding the total number of samples constant. The stream reach under consideration was again set at 100 miles and the spill characteristics established in the same manner as above. In this case, however, the number of sampling stations and the number of samples monthly per station were varied to hold the total number of samples constant at 12. From the plot in Figure 9, we can see that this should give a detection value of approximately 50 percent. The actual model output data for this trial in shown in Table 3.

The data shown in Table 3 is for two different situations: 1) with pollution events originating on the upper 20 miles of the reach; and 2) with events originating over the entire 100 mile reach. Sample locations were uniformly spaced along the 100 mile reach (for example, for four stations the mileage locations would be 25, 50, 75, and 100 miles downstream). Where only one station was used, it was located at the downstream end of the reach. Sampling times were arbitarily selected at uniform time intervals over a 30 day period. Compensation was made for the fact that the time period is finite. This insured against events going undetected due to the end of the time period.

Figure 10 is a plot of the data in Table 3. The most noticeable feature is the higher detection levels when events originate in the upper 20 miles. This is logical when it is considered that events pass a large number of sampling stations when all events originate in the upper 20 miles. The plot also illustrates the effect of number of sampling stations and frequency. However, the effect is different for the two situations considered. When spills originate over

Table 2. Effect of number of samples on detection.

	Trial							
	1	2	3	4	5	6	7	8
Total Number of Samples	2	4	8	12	16	20	25	30
Number of Pollution Events	4000	4000	4000	4000	4000	4000	4000	4000
Percent of Events Detected	6.2	16.7	39.2	52.1	60.0	71.3	75.1	83.9

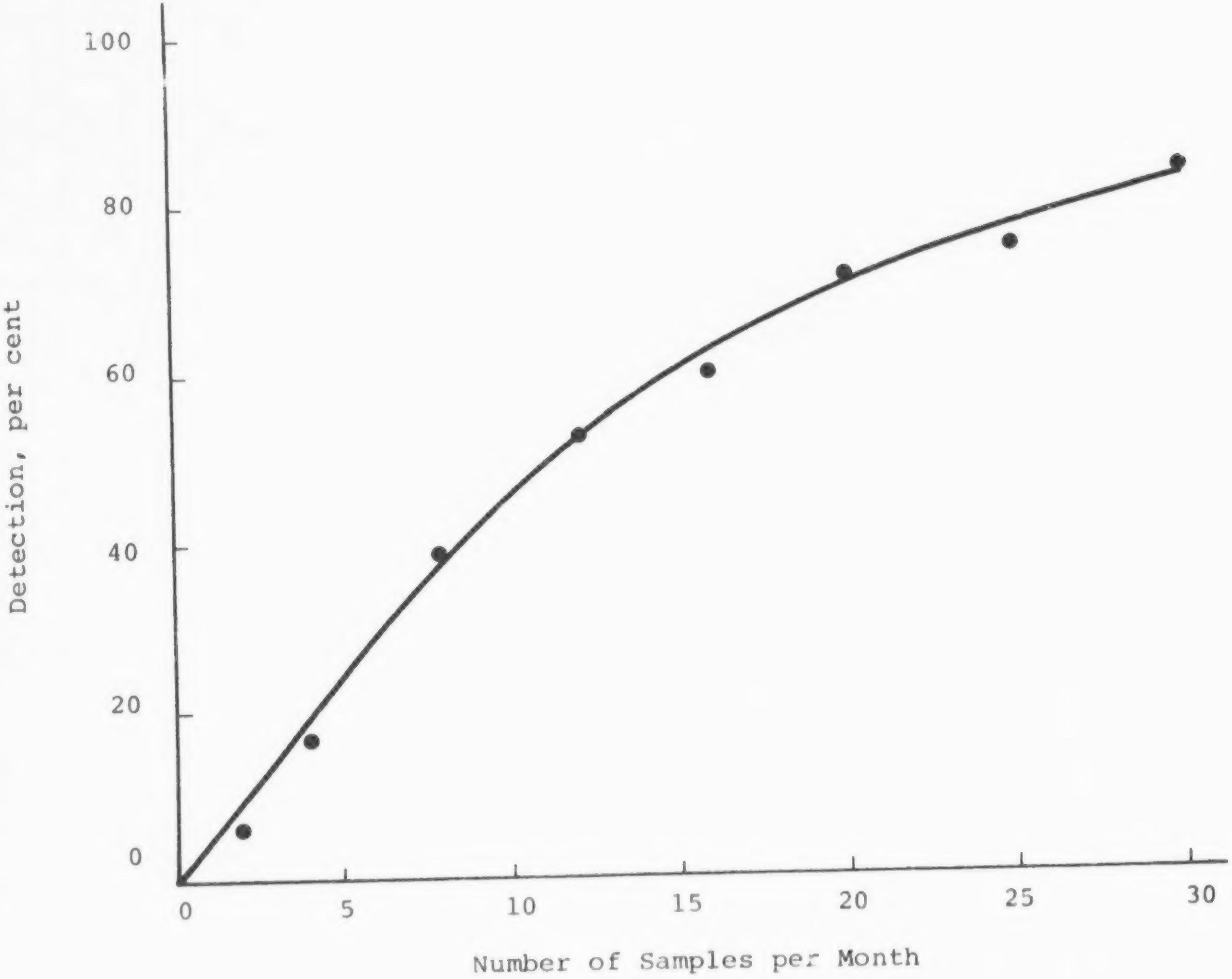

Figure 9. Detection vs number of samples for one station at lower end of reach with 0-3 day random spill duration.

Table 3. Effect of sampling frequency fnd number of stations on event detection with constant number of samples.

	Trial					
	1	2	3	4	5	6
Number of Sampling Stations	12	6	4	3	2	1
Number of Samples per Station	1	2	3	4	6	12
Total Number of Samples	12	12	12	12	12	12
Total Number of Events Tested	4000	4000	4000	4000	4000	4000
Average Detection, Per Cent						
Case 1*	32.2	32.3	34.6	38.9	40.3	49.2
Case 2	59.9	61.4	61.3	62.2	62.8	56.6

*Case 1 - events originating over entire 100 mile reach

Case 2 - events originating over upper 20 miles of 100 mile reach

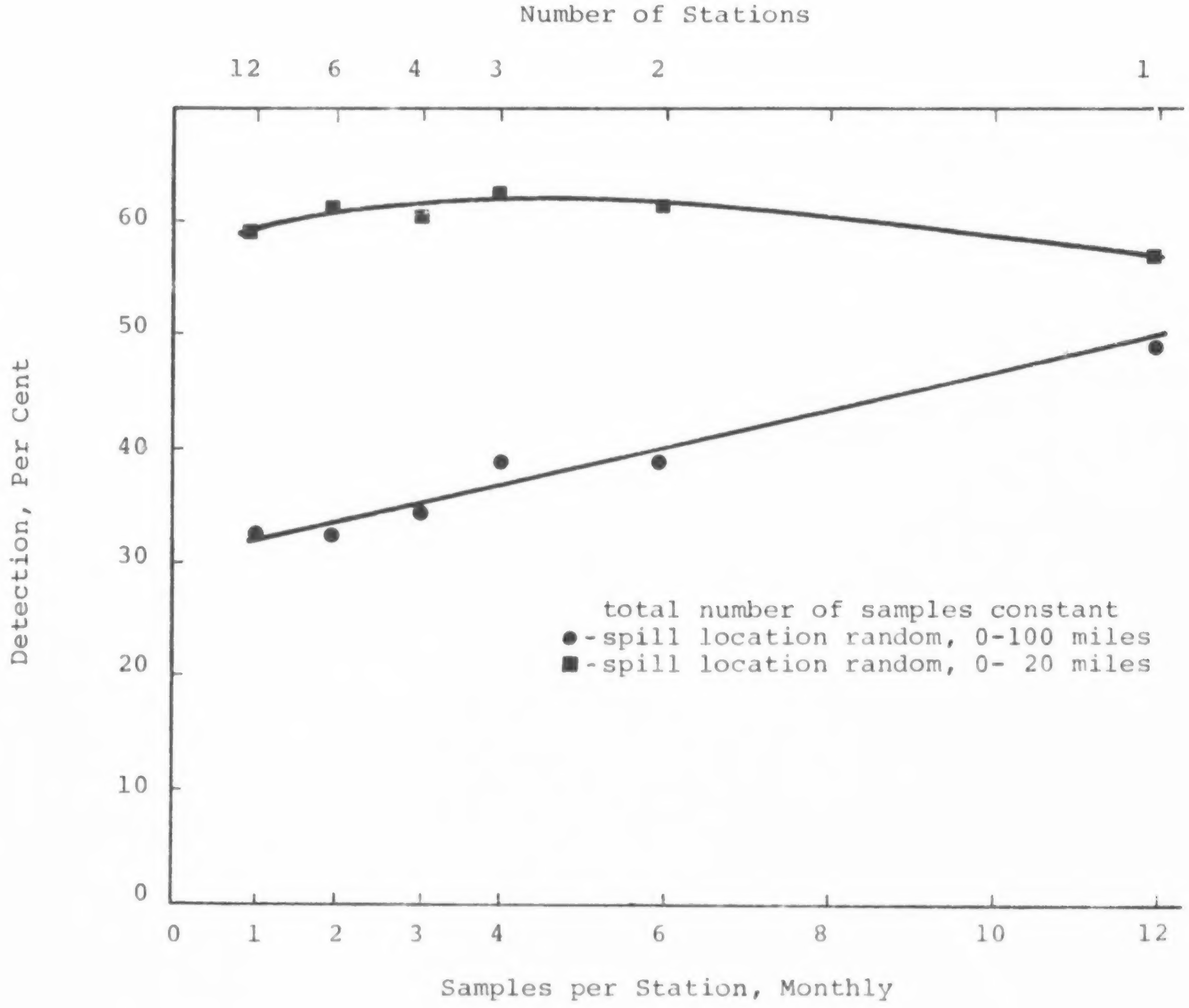

Figure 10. Detection vs number of samples per station for constant number of samples for 100 mile reach.

entire reach, detection increases almost linearly as samples per station increase. When spills originate over the upper 20 miles, there is a slight increase, then a decrease as samples per station increase.

As the number of stations is reduced, a greater number of samples are taken towards the lower end of the reach, and as the frequency per station increases, the sampling occurs more often during the time period. Both of these factors explain why the detection increases as the number of stations decreases and frequency of sampling increases. For the events originating in the upper 20 miles, detection falls off as the events have time to dissipate when a few stations are located far downstream from the sources of pollution. From this discussion, it can be concluded that fewer stations with higher sampling frequencies would better serve to detect spills than many stations with low frequency. The many stations, however, would provide a better basis for locating the pollution source once a spill has been detected.

Now an analysis will be made of the effect of spill duration on detection percentages. This information is helpful if some knowledge is known of what pollution events to expect. For this trial, a stream reach length of 20 miles was used with one sampling station specified at the lower end of the reach. Spill location was allowed to vary randomly throughout the reach, and the time interval used was 0 to 30 days. Figures 11, 12, and 13 show the results obtained from the model for this trial. Each plotted point represents the percent of events detected from a total of 1000 events. For example, 1000 events with a spill duration of 24 hours were generated occurring at random times and locations. When a sampling frequency of twice monthly was used, a detection value of 5.9 percent resulted. This process was repeated many times to obtain the plots shown. The scales used in Figures 11, 12, and 13 do not permit clear presentation of zero detection or instantaneous spills, so Figure 14 has been included to better illustrate these results. The 100 percent detection point was assumed to exist when spill duration was equal to the time interval between samples. In all cases, this plotted almost exactly on the observed line.

If information is avialble on spill durations, Figures 11, 12, 13, and 14 can be used to estimate the surveillance schedule necessary for a desired detection level. Again, however, it must be stressed that the values presented are approximations for the physical situations used in the model, but they can be useful when considered in a relative context.

To elaborate a little further on spill duration, another trial was run where spill duration was allowed to vary

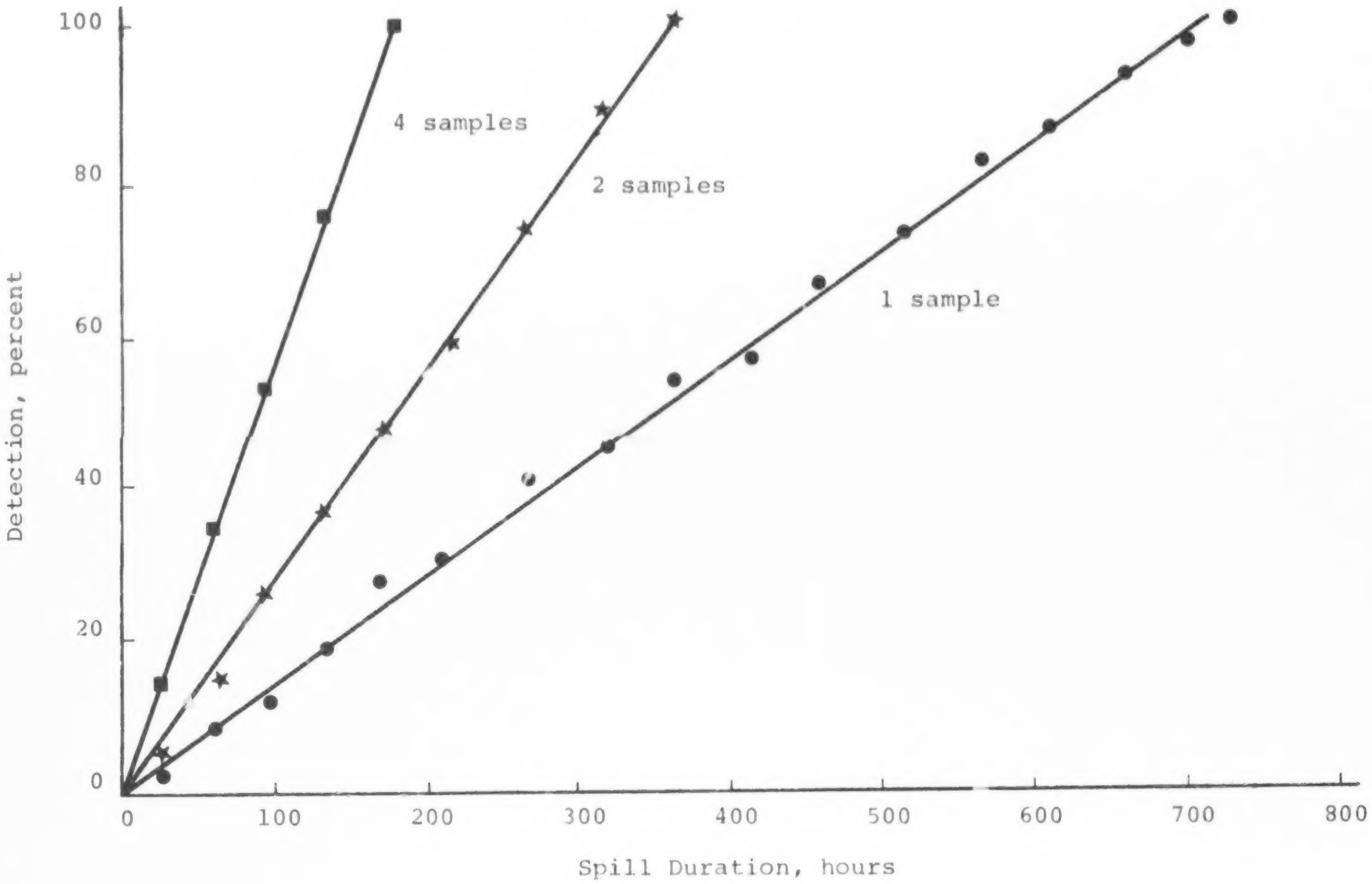

Figure 11. Spill detection by one station at end of 20 mile reach for one, two, and four samples during one month period.

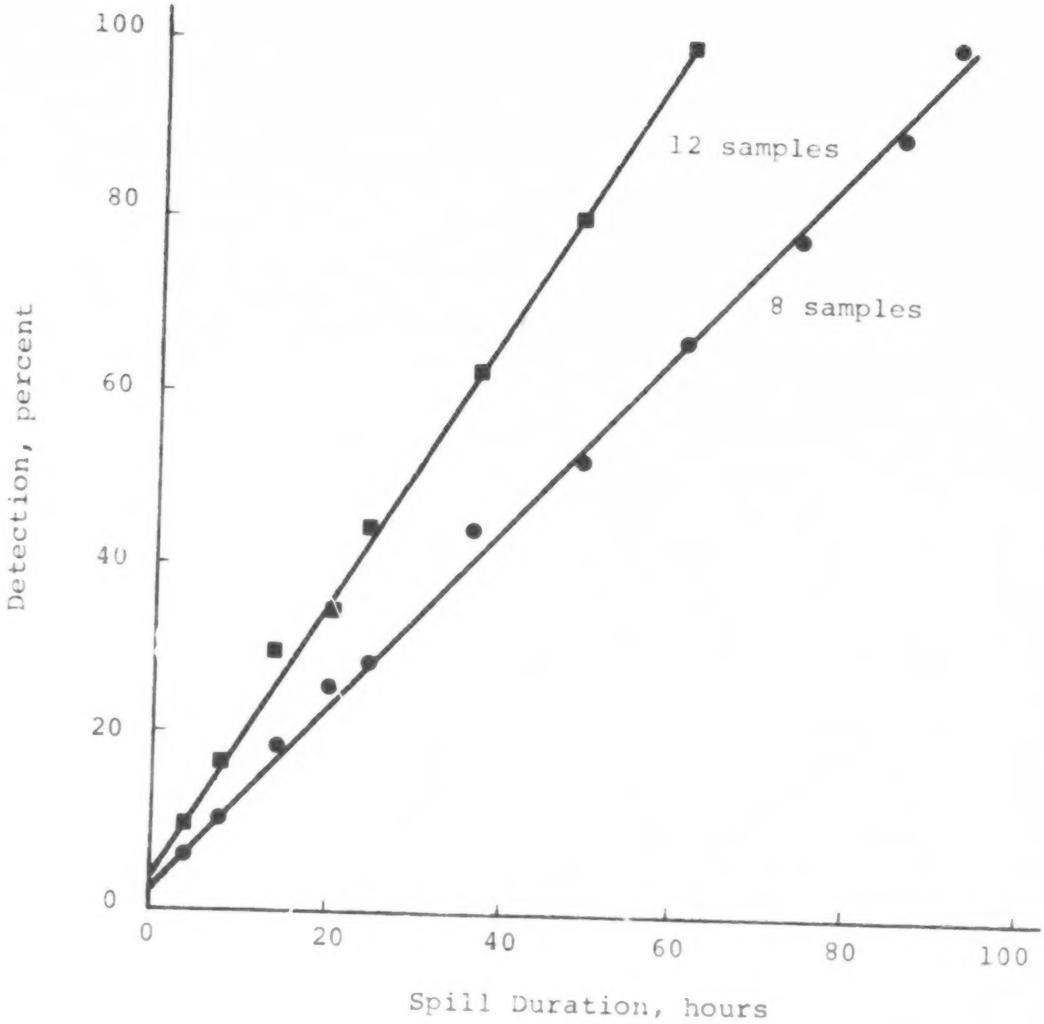

Figure 12. Spill detection by one station at end of 20 mile reach for eight and twelve samples during one month period.

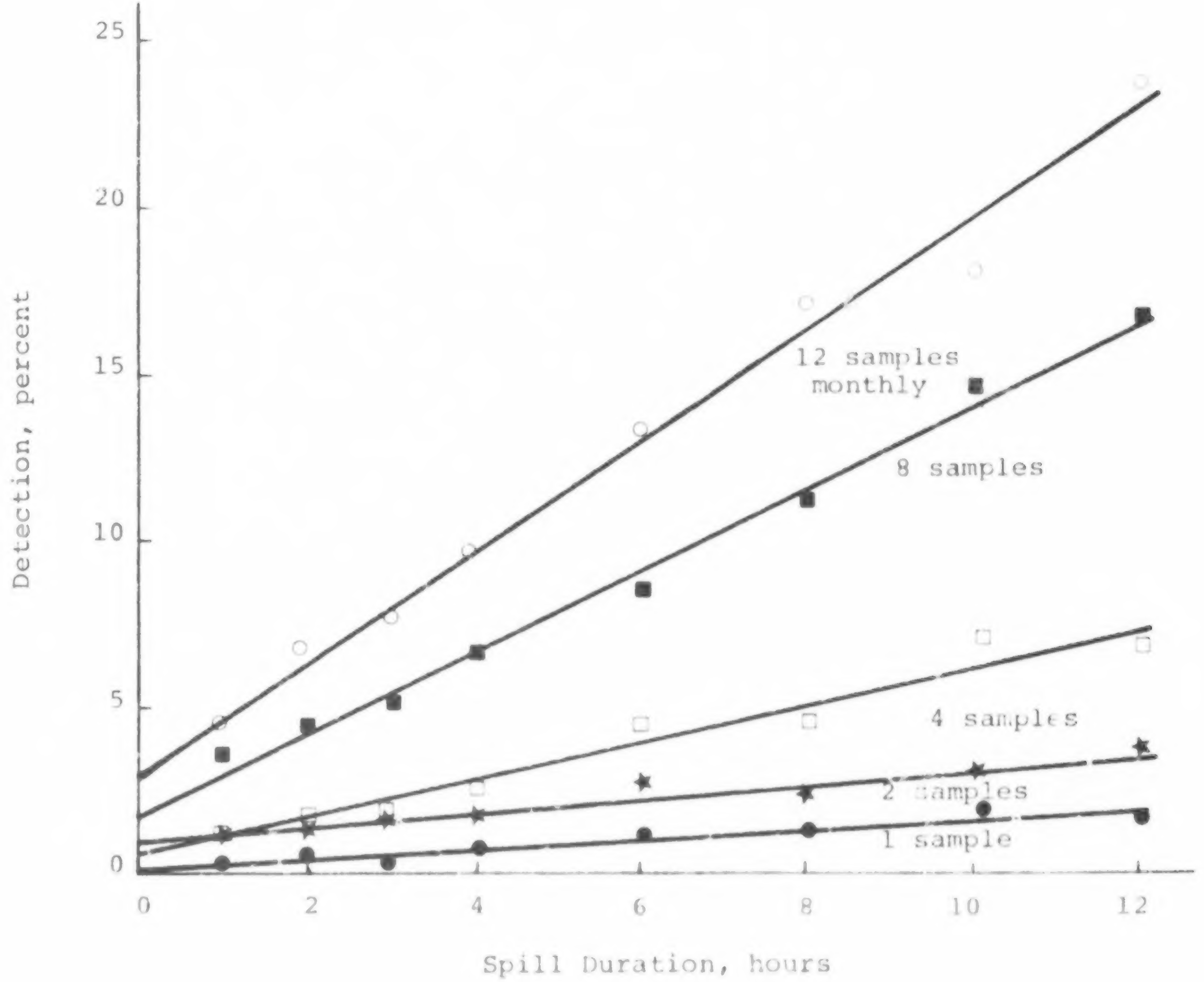

Figure 13. Spill detection by one station at end of 20 mile reach, for small spill durations and various numbers of samples during one month period.

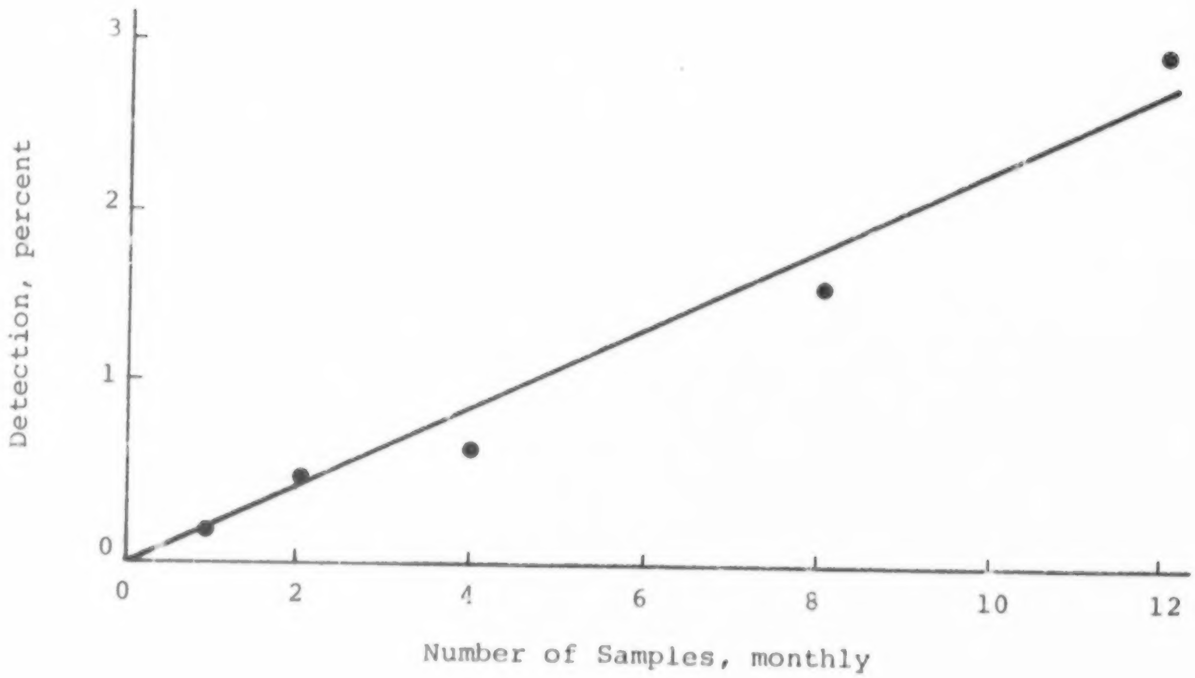

Figure 14. Detection of instantaneous spills.

randomly in several ranges rather than specified as in the preceding trial. All other factors were the same. The results of this trial are shown in Figure 15. The plot can be used in the same way as Figures 11, 12, 13, and 14, but it is not necessary to specify an exact spill duration. Figure 15 indicates, as did Figure 9, that there is, for the longer spills, a decreasing return as sampling frequency increases. The principle here is very similar to the production function concept in economics--the first few samples return considerably more information than the last few samples. The short duration spills will require sampling on the order of minutes or hours instead of days; consequently, their curves remain in low detection percentages.

The concept of information return for sampling effort can also be related to the number of sampling stations. Except for the discussion where sample totals were held constant, there has been no attempt to consider multiple sampling stations. This must be considered if there are to be general relationships developed for an entire river basin or state. It has been noted already that increasing the number of sampling points while holding the total number of samples constant reduces detection effectiveness. However, if sampling points are increased with a corresponding increase in total number of samples, the detection could be expected to increase. This relation will not necessarily be linear, since the addition of extra effort will return less and less information per unit of effort as the number of sample points and samples increases.

In order to analyze multiple sampling stations, the previous results will be utilized in the following manner. The results for one station will be modified to depict results for several stations. Due to the decreasing information returns to surveillance scale, the addition of a second station on a river will add a certain fraction of the first station's information to the total of the two stations. Figure 10 indicated that the highest detection level for one station occurs when it is sampled frequently. It is now assumed that this arrangement would supply the maximum information for one station and any others added to the river will return some fraction. Therefore, the first station is assigned a relative detection effectiveness multiplier of 1.0 and the next station will be assigned a value less than 1.0. By using relative detection effectiveness multipliers derived from Figure 10, values for effectiveness were calculated and plotted in Figure 16. This figure can now be used, along with Figure 9, to estimate the detection for a multi-station network on a given stream. The following examples are presented to illustrate

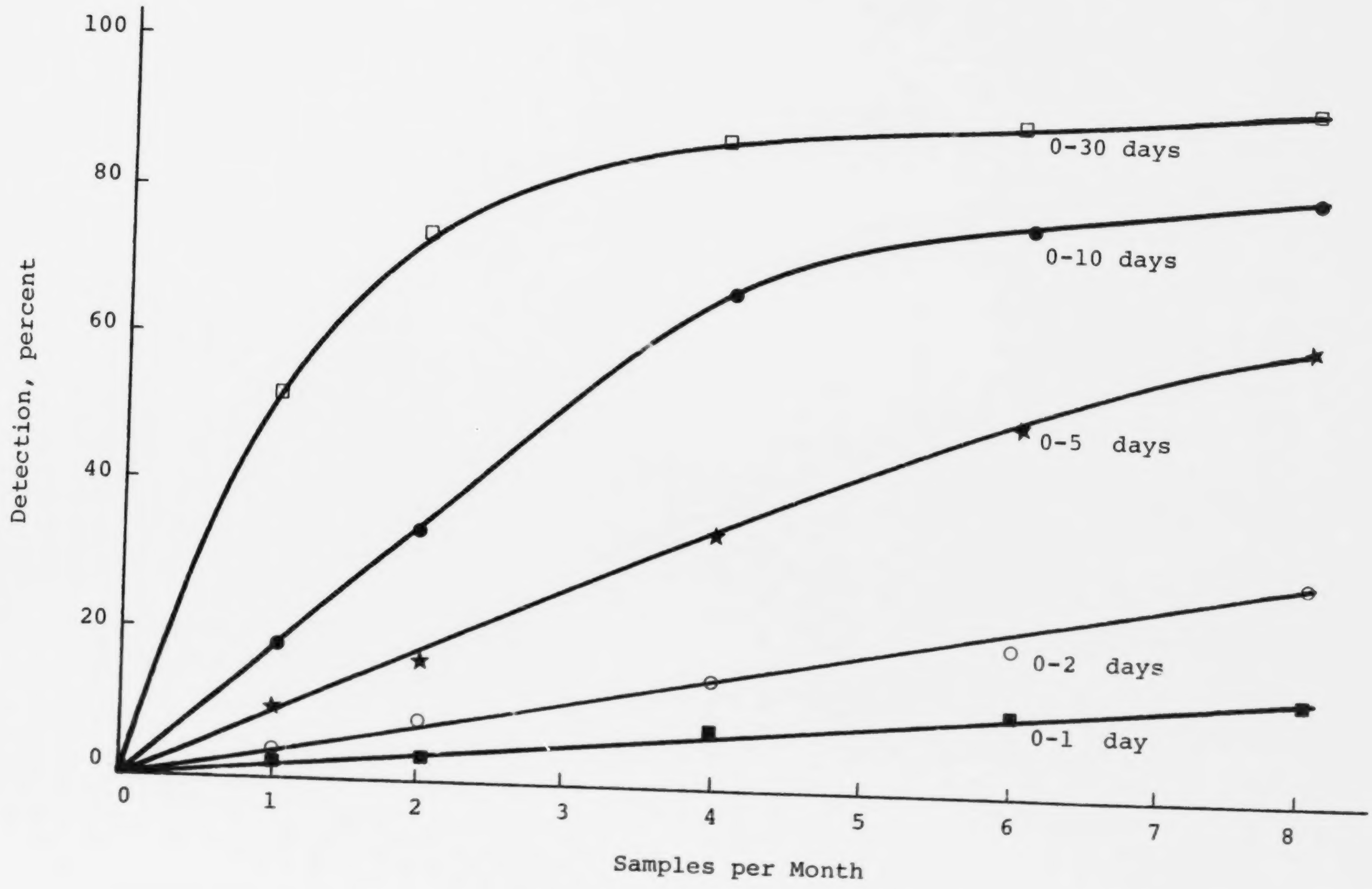

Figure 15. Detection vs sampling frequency for various spill duration ranges.

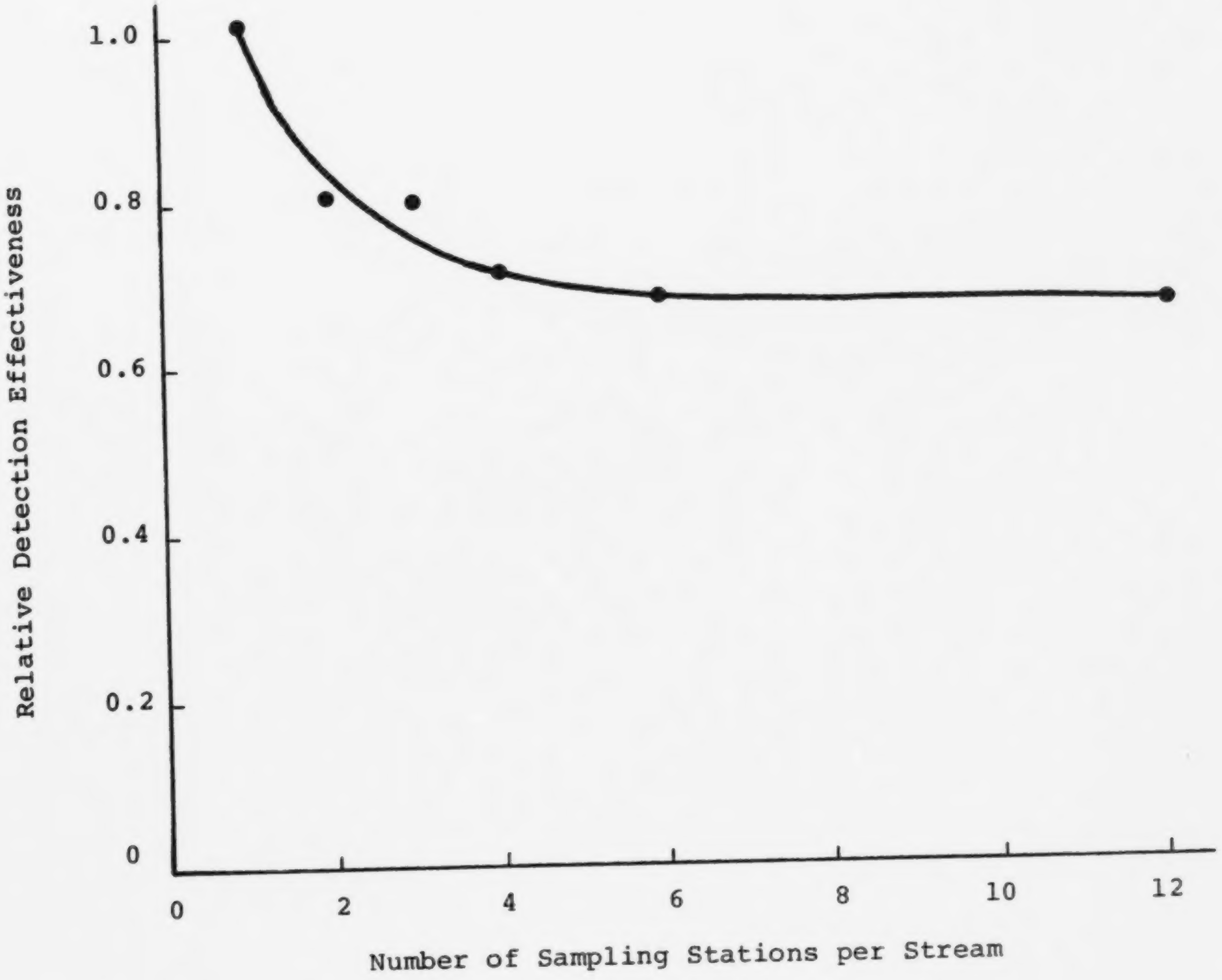

Figure 16. Detection effectiveness versus number of sampling stations per stream with a constant sampling frequency of 12 samples per year per stream.

the procedures involved. In each example, it is assumed that a minimum number of sampling points can be selected to adequately monitor the stream. This was accomplished in the stream characterization and station location sections.

For the first example, assume it has been decided to locate six sampling stations on a hypothetical stream. Each sampling station is to be sampled twice monthly, and it is important to know the detection level to be expected. From Figure 9, it can be seen that for a total of 12 samples monthly, the level of detection is approximately 52 percent. However, Figure 9 is based on the ideal situation of one station at the end of a reach. Since six stations are now being considered, the effectiveness per additional station and for the end station is reduced and the 52 percent detection value must be modified accordingly. From Figure 16, the relative effectiveness for six stations is about 0.67 (termed "relative effectiveness factor"). Multiplying 52 percent by 0.67 results in an estimated detection level for the proposed system of about 35 percent for spills in the 0 to 3 day random duration range. If spills of different durations than these were expected, the above percentages would have to be modified further using Figures 11 through 15 as guidelines.

Approaching the same situation from a different viewpoint, the question may be to determine how often the six designated stations would have to be sampled to obtain an approximate detection level of 50 percent for 0 to 3 day random duration spills. Since the relative effectiveness is again 0.67, one must divide 50 percent by 0.67 which yields a value of 75 percent. Entering Figure 9 with a 75 percent detection value indicates that approximately 24 samples monthly are necessary. Each of the six stations would be sampled about 4 times monthly to obtain the desired detection level. The decreasing return as sampling frequency increases is obvious when the two examples are compared. It was necessary to double the sampling frequency to increase detection from 35 percent to 50 percent.

Continuing to expand the analysis for spill detection, the primary network for Colorado will now be considered. The analysis will still be approached from a stream-by-stream basis. Colorado has 14 streams which have been assigned primary sampling stations. The assumption is made that a spill detection level of 50 percent is desired on these primary stations. Table 4 lists the streams and the number of primary stations on each. From the table it is noted that 191 samples per month are needed from the 22 primary stations. This averages to 8.68 samples per station monthly.

Table 4. Primary network analysis results for Colorado.

River or Stream	Number of Stations	Relative Effectiveness (Figure 40)	Absolute Detection Necessary	Total Samples Per Month (Figure 33)
Arkansas River	3	0.75	67	18
Fountain Creek	1	1.00	50	12
Colorado River	2	0.83	60	15
Eagle River	1	1.00	50	12
Roaring Fork River	1	1.00	50	12
Gunnison River	1	1.00	50	12
Uncompahgre River	1	1.00	50	12
South Platte River	4	0.72	70	20
Cache La Poudre River	1	1.00	50	12
Big Thompson	1	1.00	50	12
St. Vrain	1	1.00	50	12
Boulder Creek	1	1.00	50	12
Clear Creek	3	0.75	67	18
Bear Creek	1	1.00	50	12
	22			191

Table 5 . Sampling frequency compared to effectiveness levels for Colorado's primary network.

Effectiveness Level	Total Samples Per Month	Samples Per Station Per Month
10	32	1
20	63	3
30	106	5
40	141	6
50	191	9
60	251	11
70	346	16

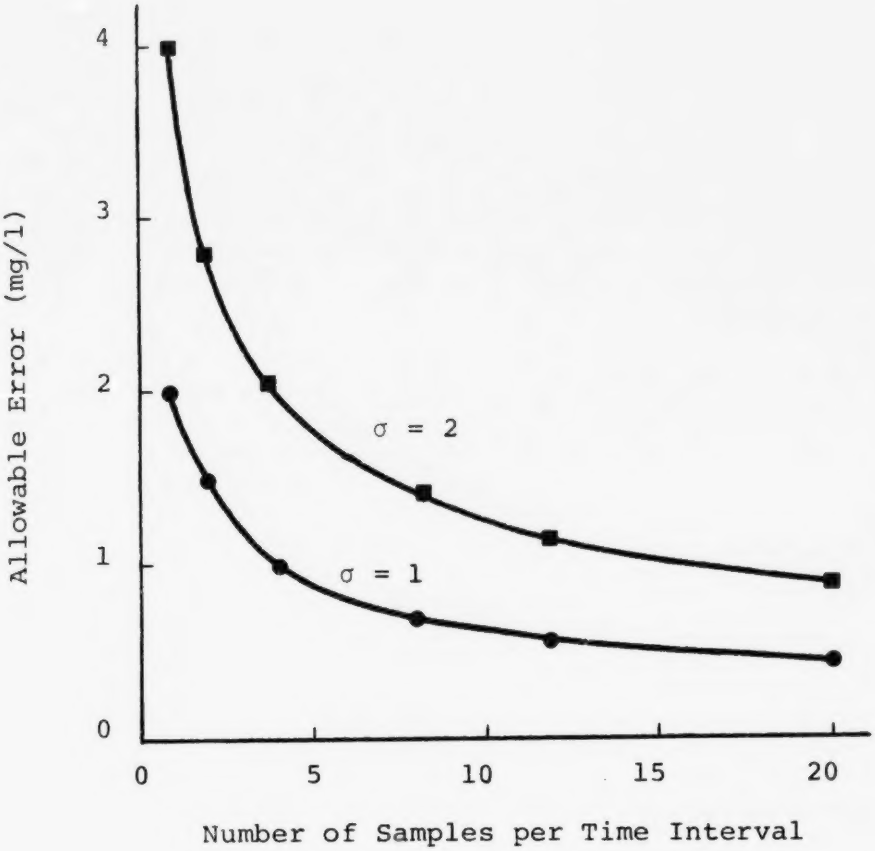

Figure 17. Number of samples vs allowable error for σ equal one and two.

On a statewide basis for Colorado, approximately 9 samples per station per month are needed to achieve a detection of 50 percent. Obviously, some streams will be above and some below the desired level if an average figure such as this is used. Those streams with several stations will have higher detection levels. This may be highly desirable in looking at the total situation.

Nine samples per month seems rather high; therefore, the questions becomes what level of detection can be obtained with one, two, four or more samples per month. The same analysis used in Table 4 has been completed for other levels of detection, and the results are presented in Table 5. Table 5 spells out very clearly the trade offs between the level of 0 to 3 day spill detection (effectiveness level) and frequency of sampling for the primary surveillance network in Colorado. These results will be analyzed further in the next section, but before leaving the topic of frequency versus effectiveness, the subject of the trend data needs to be analyzed in order to evaluate the effectiveness of the secondary stations.

As mentioned in the previous section, two approaches are used in analyzing base level or trend data surveillance systems: 1) a statistical approach; and 2) a model approach. For the statistical approach, the annual mean is used as the representative characteristic for base level quality data. Any time period could be used, but for purposes of illustration, the annual mean was selected.

Figures 17, 18, 19, and 20 are plots of points computed using the statistical formula described in the previous section. As with the previous frequency versus effectiveness plots, these Figures do not refer to any specific parameter but are generalized to permit broad application. Use of the curves requires some previous knowledge of the variability of the data to be collected. This was the purpose of the stream characterizations.

Knowing the variance or standard deviation for a parameter of concern, the proper curve can be selected from the Figures. For a given number of samples, then, the ordinate value for the allowable error at a 95 percent confidence level can be read. For that number of samples, one can expect to be within the allowable error of the true mean 95 percent of the time.

At this point, a hypothetical example might aid in use of the Figures. Consider a parameter for which the available data shows an annual mean of 50 mg/l and a standard deviation of 25 mg/l. The question becomes how many observations yearly are necessary to estimate the annual mean within ±10 mg/l with a 5 percent risk that the error will exceed 10 mg/l.

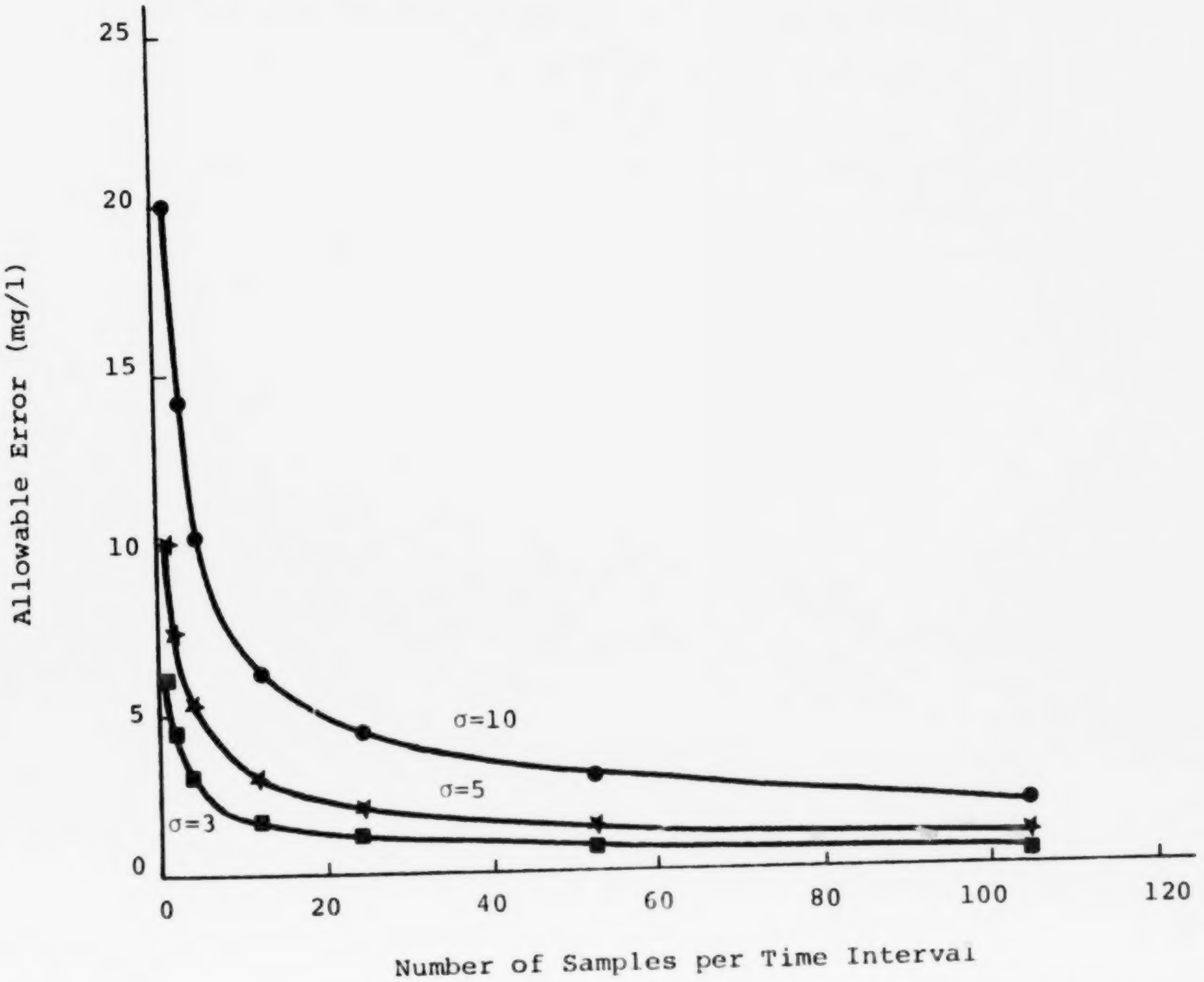

Figure 18. Number of samples vs allowable error for σ equal three, five, and ten.

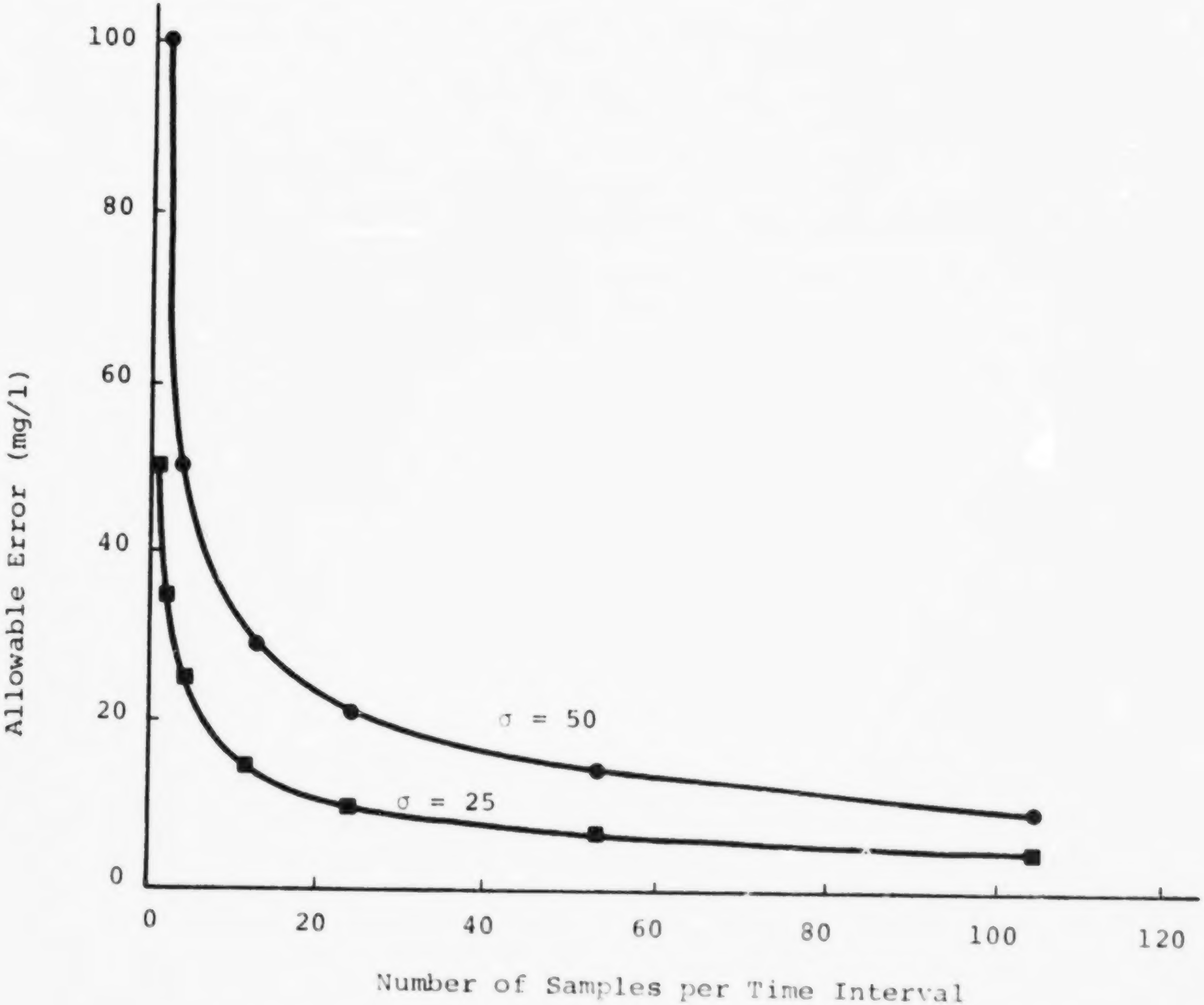

Figure 19. Number of samples vs allowable error for σ equal 25 and 50.

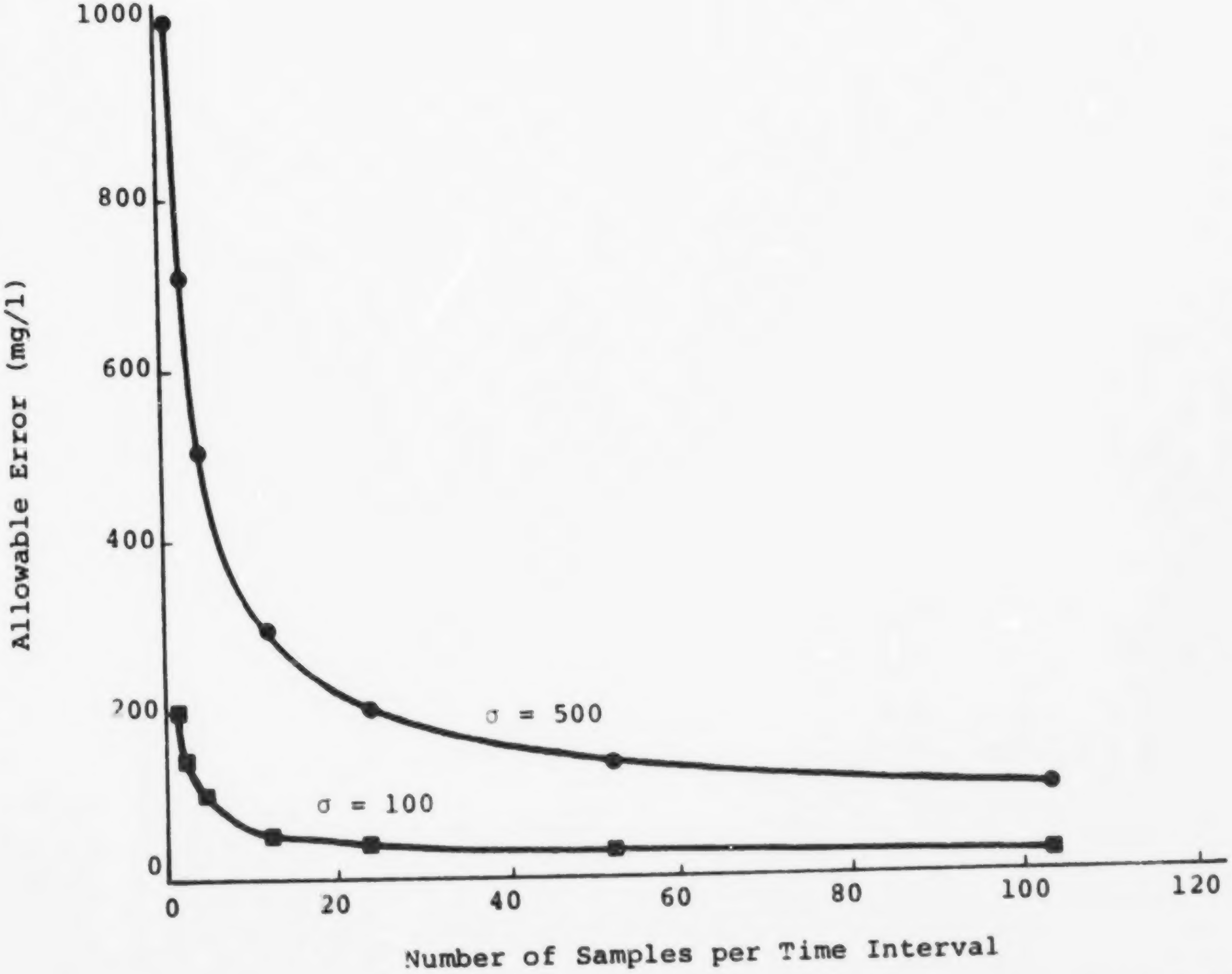

Figure 20. Number of samples vs allowable error for σ equal 100 and 500.

Selecting the appropriate curve, it can be found that 24 observations yearly or a frequency of 2 samples monthly is necessary. If this were raised to an allowable error of 15 mg/l, it would only be necessary to sample once monthly. Note that it was not necessary to use the value for the mean. The standard deviation is the only data characteristic necessary and the values obtained from the curve are valid if the mean is 50 mg/l or 50,000 mg/l. The mean is really only of concern in deciding what a reasonable value for the allowable error might be. It should also be emphasized that individual observations will commonly exceed the allowable error and that only the mean of these observations is being considered.

These curves can also be used to evaluate a monitoring system or to evaluate data obtained from a system. Considering the latter, one can make the statement that if an observed mean greatly exceeds the allowable error for the given data and system characteristics, additional observation is desirable. The large deviation may be due to an actual significant change in water quality. Since the annual means are obtained from historical data, deviation for a given year from previous annual means may be due to long-term trends. Judgment and additional study would be necessary to determine the cause of the deviation.

To estimate the performance of an established surveillance system or schedule, the Figures are entered with the known sampling frequency and standard deviation for the parameter of concern. The allowable error can then be read directly. This allowable error value is an estimate of the accuracy of the system in obtaining mean values for the parameter for the time period.

The model approach will now basically serve to further illustrate the results of the statistical approach. A time period of one year was selected and the mean for that period or the annual mean was used as a basis of comparison. For each run, a data set was generated consisting of daily values for a total of 10 years. The generated data was random, normally distributed about a specified mean, and had a specified standard deviation. The specified mean of the generated data was shifted each year to simulate a long-term trend.

Various sampling schedules were tested to determine their ability to predict the annual mean within the allowable error for the given conditions. Sampling internals tested were 5, 10, 15, 30, 60, and 90 days. The observed data values were those values of the generated data occurring on a day when sampling was scheduled. For each year, an annual mean was calculated from the observed values and compared to the mean of the generated data. For the results shown, the specified mean and standard deviation of the generated data for the first year were 35 mg/l and 3 mg/l respectively. The specified mean was increased by 1 mg/l each year and the standard deviation held constant.

Table 6 is a summary of the results of these tests. The specified standard deviation of the population was used to compute the allowable error. The allowable error could also have been read directly from Figure 18. The deviation of the observed annual means from the true mean of the generated data is compared to the allowable error. The statistical approach stated that it should not exceed the allowable error over 5 percent of the time. As shown in the table, the allowable error was exceeded 3 times in 60 trials, which is exactly 5 percent.

Figure 21 has been included to show how the deviation of the observed from the true mean decreases with increased sampling frequency. Although the data shown in this figure is only applicable to the particular situation specified in the model, it does point out the type of relationship to be expected between sampling frequency and accuracy.

The results presented in the foregoing discussion will now be applied to Colorado to analyze sampling frequency versus effectiveness for the proposed secondary network. The results presented are for one station only; therefore, the analysis will have to be summarized in order to consider a statewide network of secondary sampling stations.

The analysis requires that parameter's expected means and standard deviations be used as a basis for sampling frequency selection. Ideally, all parameters should be included in the analysis, but this would make the procedure extremely laborious. Therefore, the procedure proposed is to select three or four important parameters and to revolve the analysis around these. More could be chosen if more accuracy is sought.

Knowing the variability of a given parameter permits the selection of a desired accuracy limit or allowable error to be permitted in the data collection. With these arguments, the Figures are entered and a value for the number of samples at a station for the time period under consideration is read. This value is converted to a sampling frequency. If four parameters are considered, the average of the frequencies obtained is the compromise sampling frequency for the network under consideration.

Table 6. Base level surveillance model results.

Sampling Interval, Days	Number of Samples Per Year	S.D. of Population	Allowable Error mg/l	Number of Trials	Number of Times Allowable Error Exceeded
5	73	3.0	0.70	10	0
10	37	3.0	0.99	10	0
15	25	3.0	1.20	10	1
30	13	3.0	1.66	10	1
60	7	3.0	2.27	10	0
90	5	3.0	2.68	10	1
			Total	60	3

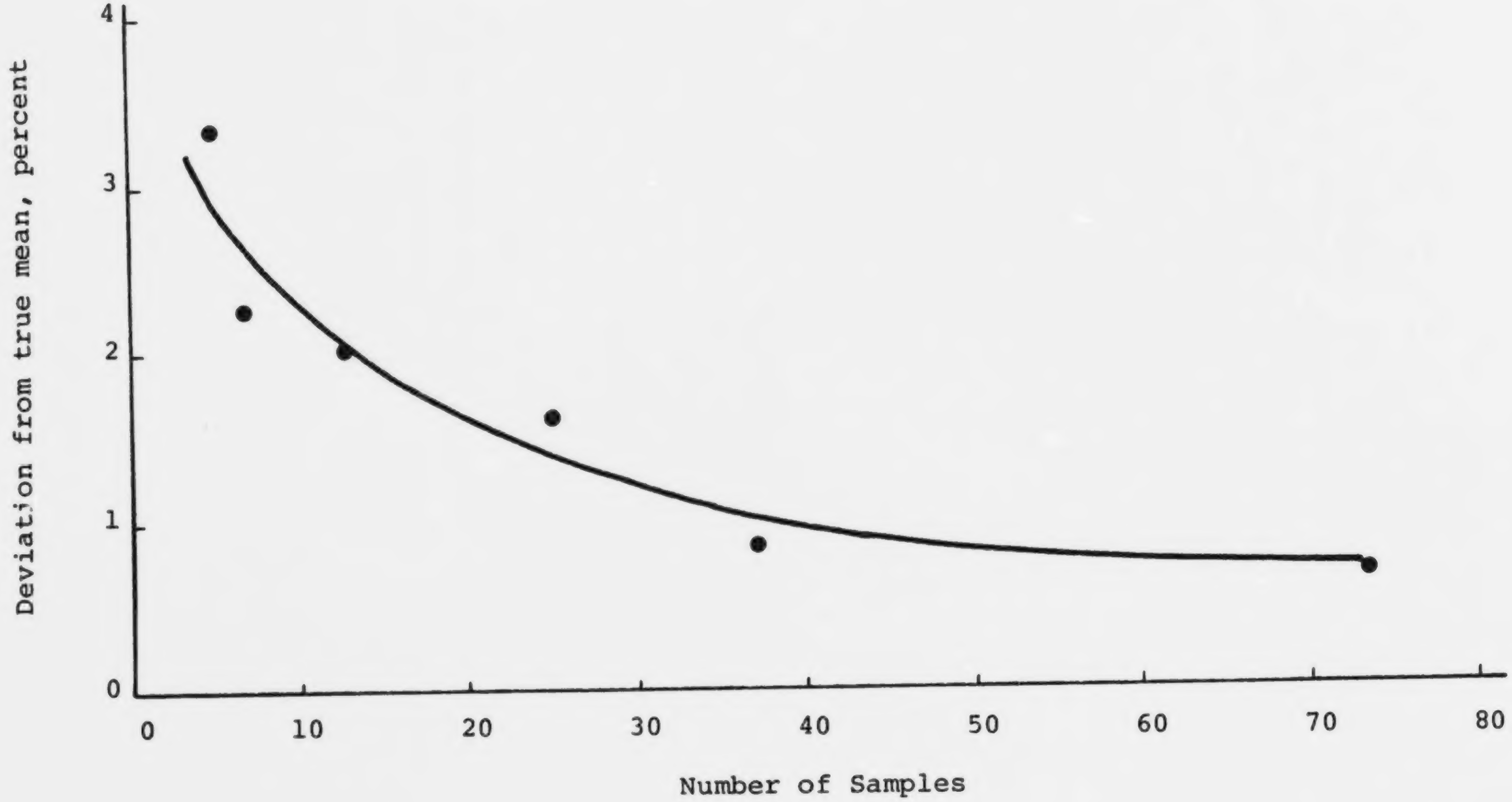

Figure 21. Observed deviation from true mean.

As mentioned earlier, the analysis is for one station, therefore to consider all stations in a state will require the selection of one of two approaches. Either each station must be analyzed and the resulting frequencies averaged, or the means and standard deviations must be averaged and the analysis performed once. The latter approach was chosen for this application to Colorado. For this particular analysis, DO, pH, and TDS are chosen as the parameters to be considered. By averaging the means and standard deviations listed under the stream characterizations for Colorado, an average mean and standard deviation for the state for each parameter can be obtained. The results are as follows:

Parameter	Mean	Standard Deviation	Accuracy Limit	Necessary No. of Samples (From Figures 17&20)
DO	7.62	1.90	3.81	1
pH	8.01	.44	4.01	1
TDS	813.25	314.86	406.63	3
				5

For purposes of illustration an accuracy limit of 50 percent of the mean and a period of study of one year will be selected. Therefore, by taking one-half of each mean, the accuracy limit or allowable error is determined. The total number of samples needed for all parameters (five in this case) is then divided by the number of parameters (3) to give the average number of samples necessary for the accuracy limit and period involved. For the above situation, this is 1.67 or 2 samples per year, or one sample each six months. It can now be said that for these parameters, sampling twice a year will result in annual mean values within 50 percent of the true mean with a 5 percent chance of exceeding this limit.

By calculating the sampling frequencies for various limits of accuracy, the water quality manager can obtain an excellent view of how his decisions on frequency influence his information gain. In Table 7, the frequencies are presented for accuracy limits from 10 to 100 percent. The frequencies are presented in whole numbers which required rounding of the numbers. The results of Table 7 illustrate very clearly that the closer to the true mean one gets, the many more samples he will have to collect. The needed relationship between frequency and "effectiveness" has now been obtained for the secondary network.

In summary, the Figures and Tables presented in this subsection are included for use in relating sampling frequency

Table 7. Number of samples required for various accuracy limits for Colorado's secondary network.

Accuracy Limit	Number of Samples Per Year Per Station
10%	25
20	7
30	4
40	3
50	2
60	1
70	1
80	1
90	1
100	1

to effectiveness. This should be a very useful aid in itself in planning and evaluating water quality monitoring systems. The Figures and Tables are highly generalized and, consequently, should be applicable to a wide variety of situations.

As with any generalized guidelines, however, use must be combined with a certain amount of judgment. Individual situations may have characteristics which dictate more or less stringent sampling requirements than those indicated by this data.

Certain arbitrary decisions are also necessary for use of these guidelines. For example, if one is trying to decide what sampling frequency is necessary in a given situation, the decision must first be made as to what the magnitude of the allowable error will be. Different quality parameters may indicate different sampling frequencies, so the relative importance of the various parameters must be weighed. When sampling frequency decreases, the decision of when the samples should be taken becomes more important. This particular decision can be aided by the use of historical data indicating when extremes or approximately average conditions are likely to occur.

With the grab sampling
ness relationships now available, the grab sampling frequency versus cost must be obtained. Analyses of automatic monitoring and remote sensing will follow the grab sampling discussion.

Cost Analysis

In order to obtain accurate cost estimates for the grab sampling cost-effectiveness analysis, cost data was obtained from the Water Pollution Control Division (WPCD). Since the WPCD is in the Colorado Department of Health, the laboratory analyses are performed in the Department's general labs. The WPCD contributes to the staff and some to laboratory supplies but in no way pays for the entire laboratory operation. Because of this, the cost figures may be low when compared to a laboratory established only for water quality sample analysis with all costs being assigned to these samples. Cost figures for automatic monitoring and remote sensing will be presented when they are discussed as possible replacements for parts of the grab sampling network.

Determination of the total grab sampling cost was accomplished in three parts. The first part, collection, included costs for salaries, mileage, equipment amortization, travel expenses, and shipping of samples to the laboratory. The total annual cost, $33,460, for collection was then divided by 1560, the total annual number of samples per year, to arrive at a general cost estimate of $21.40 per sample per year for collection.

The estimate for laboratory cost per sample included annual yearly costs for three chemist salaries and a fixed sum ($4,400) for laboratory support. Since the WPCD utilizes bacterial and radiological expertise of the state lab, cost estimates were also included for these items. The total annual lab cost, $54,210, was then divided by the total number of samples, 1560, to obtain a general laboratory analysis cost estimate of $34.80 per sample.

The third portion of the total cost is that associated with posting and storing the data. At the WPCD, this includes the full time of one engineer and one-half of a secretary's time. Also, the WPCD is currently using the STORET system and is renting a terminal. Total annual cost is $15,880 with a cost per sample of $10.18. This third cost factor is highly variable from agency to agency, depending upon the effort devoted to data analysis.

The total cost per grab sample, therefore, is $66.38. Again, it cannot be overemphasized that this cost is for Colorado, and there are certain aspects of the Colorado situation which play a very important role in the final figures.

In the following analysis, it will be assumed that there is a straight line relationship between cost and number of samples. There are many factors which could affect this but to determine the true nature of these effects would require a detailed economic analysis. A detailed economic analysis at this point would be of marginal value when used in conjunction with the general water quality trend data.

For the analysis, the cost per sample will be rounded to $70 per sample. In Figure 22 the cost, using $70 per sample, is plotted against total number of samples. This now yields a cost versus number of samples (frequency) which can be combined with the frequency versus effectiveness relationship to give the desired cost-effectiveness results.

Surveillance Effectiveness Versus Cost

The results of the previous two sub-sections on grab sampling can now be combined to develop the information necessary to provide the basis for rational decision making associated with

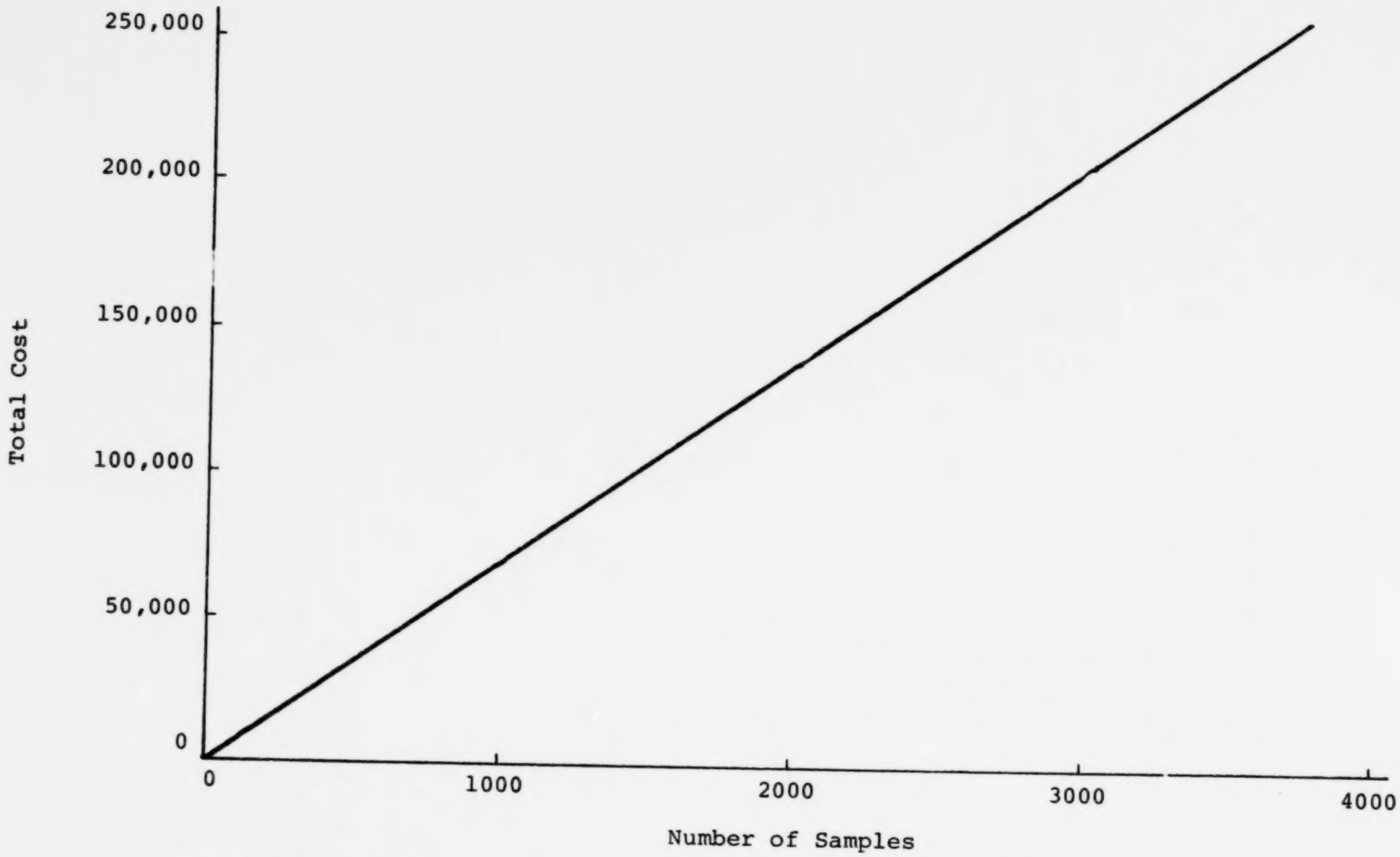

Figure 22. Relationship of cost to number of samples for Colorado.

water quality management at the state level with respect to grab sampling data acquisition. The results of Table 5 can be combined with the results of Figure 9 in order to associate effectiveness to cost for the primary network. The results are shown in Table 8. The calculations were not carried beyond the 70 percent effectiveness level since the number of samples is increasing past the point of reality. The exponential nature of the curve indicates that the extra cost for each 10 percent increase in effectiveness is so large that an alternative must be considered. In other words, the cost involved is not worth the returns generated. This illustrates very clearly the principle of diminishing returns. It must also be remembered that the costs discussed here are for the primary grab sampling network only.

Figure 23 illustrates the relationship between effort expended and benefits gained for the primary network in Colorado for a 0 to 3 day spill length. The information presented in the figure can be very helpful in deciding where to spend limited funds, especially if similar curves were available for other aspects of the total program. The water quality manager would then have a very good basis for expending funds in certain areas to the exclusion of others. He would concentrate his effort in those areas where he had the greatest return. This would then yield the most effective overall program for the money expended.

The 0 to 3 day spill length used in the analysis was chosen because it was felt that this length would be most representative of the majority of spills. If more specific information were available on expected spill lengths, then the analysis could be repeated. If a longer spill length is used, the curve would tend to flatten out. This would result in more effectiveness at a given level of cost. Specific information on expected spill length could be obtained in a comprehensive waste outfall inventory.

Considering the high costs involved in obtaining the last percentage points of effectiveness, it would be very appropriate to seek alternatives which, hopefully, would supply the higher effectiveness levels at a lower cost. It is at this point that automatic monitoring and remote sensing may prove valuable in a surveillance effort. However, before getting into the analysis of these other techniques, the secondary grab sampling network must be considered.

In analyzing cost-effectiveness for the secondary network, the results of the past two sub-sections are again used. Using the number of samples per station needed for certain levels of accuracy, the total number of secondary samples

Table 8. Effectiveness versus cost for the primary surveillance netowrk in Colorado.

Effectiveness Level	Yearly Number of Samples	Yearly Cost
10	384	$26,880
20	756	52,920
30	1272	89,040
40	1692	118,440
50	2292	160,440
60	3012	217,840
70	4152	290,640

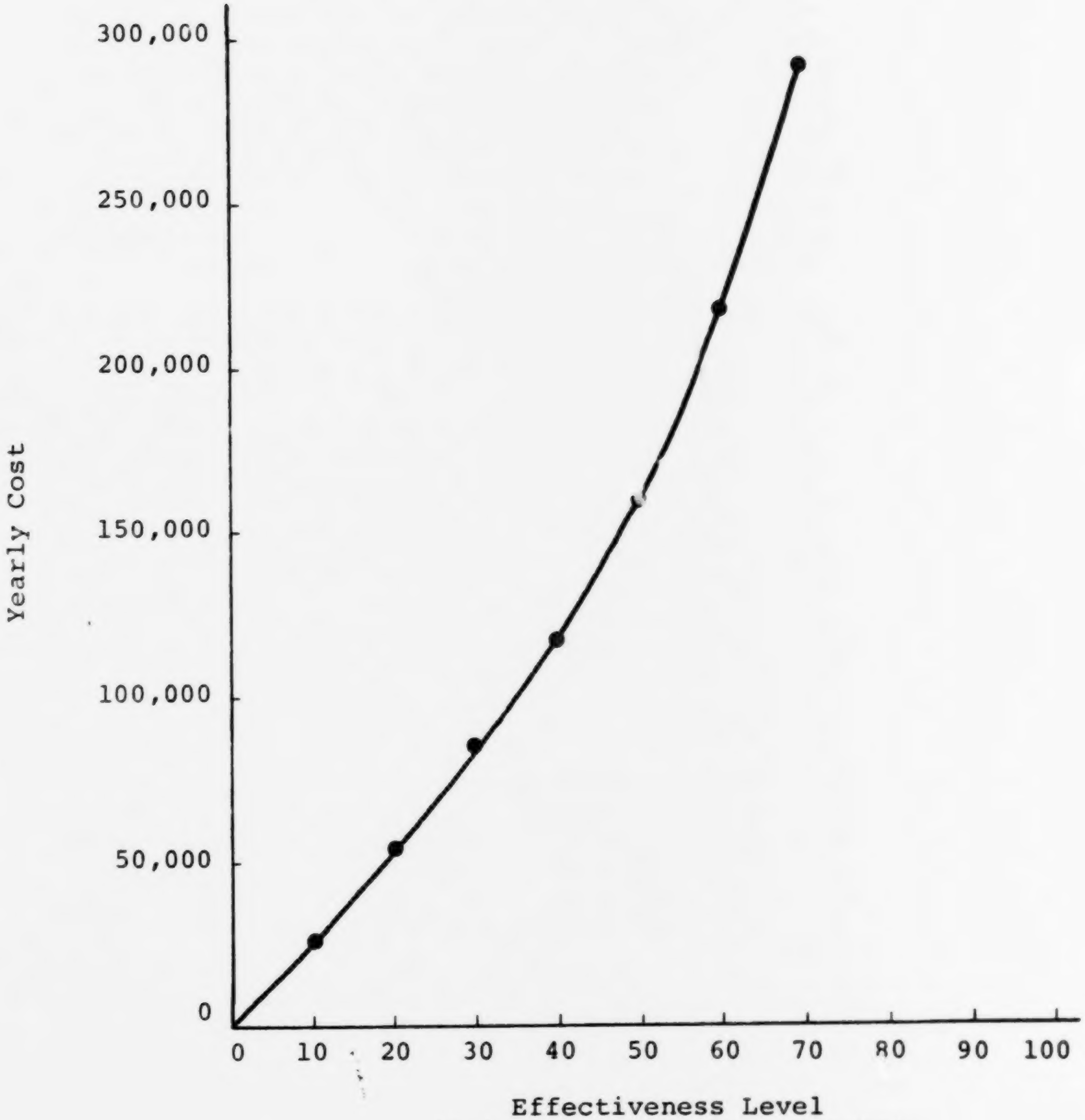

Figure 23 Cost-effectiveness results for the primary network in Colorado for a 0-3 day spill length.

per year can be obtained by multiplying by the number of secondary stations. For this analysis, Colorado is assumed to have the same number of stations as listed in the stream characterizations. This is not entirely correct as Colorado has recently expanded their network. In the stream characterization sub-section, 82 stations are listed since all primary stations can also be used as secondary stations. Using the figure of 82 and the sampling frequencies obtained earlier for the secondary network, the total yearly samples necessary for various accuracy levels can be calculated. The results of these calculations are given in Table 9 along with the yearly cost associated with the number of samples. The cost versus accuracy level is presented in Figure 24. This figure again presents a valuable tool to the water quality manager in that he has an excellent view of the tradeoffs available to him with respect to the secondary network.

The results presented in Figures 23 and 24 permit the design of a grab sampling surveillance network for Colorado with due consideration of the cost constraint involved. It is not very realistic for a researcher to sit at his desk and decide the optimum network for Colorado since the real life situation is removed. It is for this reason that the results of the research are presented in a form that a manager can use. In order to illustrate the use of these results, assume that Colorado has $350,000 to spend on surveillance for the next year. The question to be answered is how should this money be spent in order to best meet the data needs of the WPCD and how should it be allotted to obtain the most information for the given resources. According to the strategy determination, approximately 45 percent of this should go to prevention (the secondary network) while 55 percent or $192,500 should go to abatement (the primary network).

Entering Figure 23 at the $192,500 cost figure indicates that the effectiveness level will be approximately 57 percent for the primary network. This implies that the total number of samples for the primary network should be approximately 2790 or approximately 127 samples per station per year. This breaks down to an average of 10 samples per month for each primary station.

Continuing the assumed budget example, the secondary network would receive $157,500 for the year. Entering Figure 24 at this figure indicates an accuracy level near 10 percent for the secondary network. This transforms into approximately 2050 samples per year, or 25 samples per year per station for a frequency of 2 samples per month.

The above example assumed a given budget and then the problem was to maximize returns. If the level of returns was specified, say 60 percent effectiveness for the primary

Table 9. Effectiveness versus cost for the secondary surveillance network in Colorado.

Accuracy Limit	Yearly Nunber of Samples	Yearly Cost
10	2050	$143,500
20	574	37,180
30	328	22,960
40	246	17,220
50	164	11,480
60	82	5,740
70	82	5,740
80	82	5,740
90	82	5,740
100	82	5,740

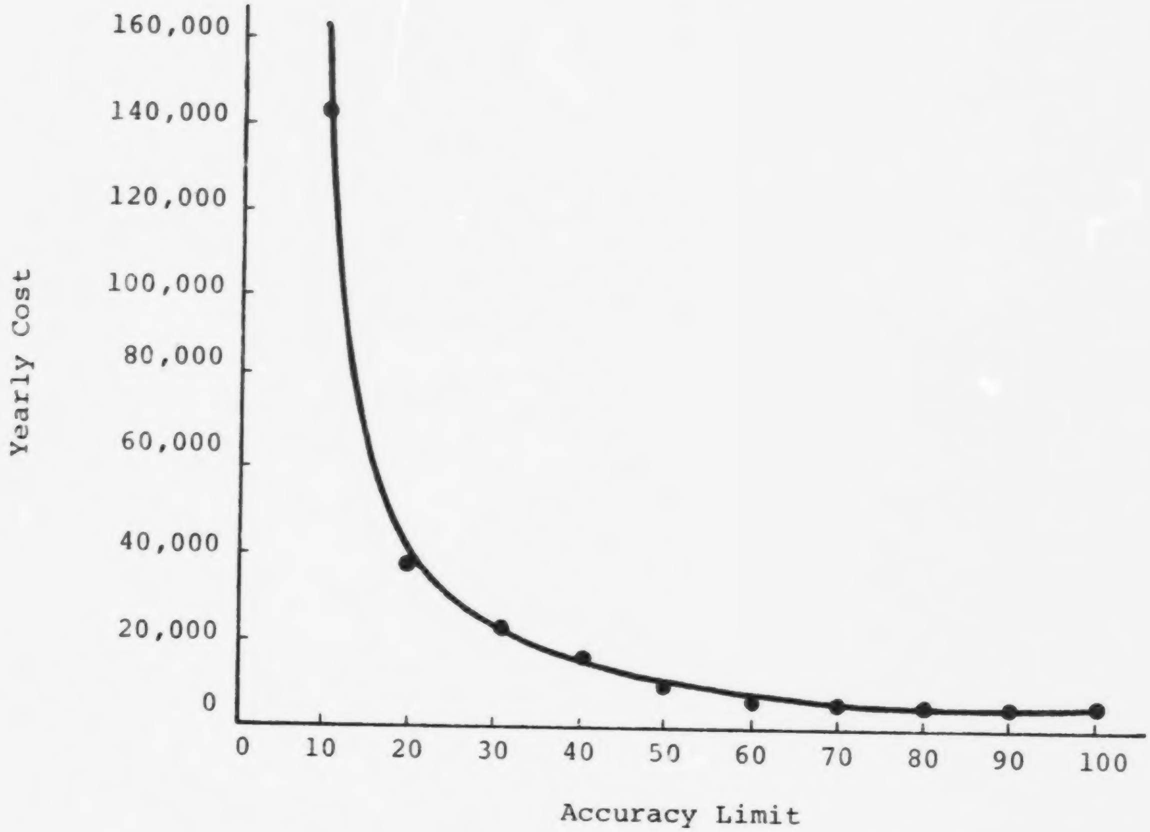

Figure 24 . Accuracy limit vs cost for the secondary network in Colorado.

network and a 20 percent accuracy level for the secondary network, the analysis could be run the other way and a cost figure could be developed. The approach would be similar to the above example.

The above example, besides illustrating the technique of using the report's results, also indicates that as an agency reaches the maximum effectiveness level in both networks, it must re-evaluate the technique used. In other words, the assumed budget in the example pushes the agency near the maximum effectiveness level for grab sampling in both networks. Any additional money obtained would return little additional information if grab sampling is maintained as the only data gathering technique. Therefore, it would be at this point that the agency should implement other techniques of data gathering such as automatic monitors or remote sensing.

Grab Sampling Parameters

The decision of which parameters to measure can be influenced by many factors. The technique of sampling can be the most restricting element in deciding which parameters to measure. Automatic monitoring, as noted in the state-of-the-art paper, has technological limitations on the parameters to be measured. So does remote sensing. Grab sampling, however, is not limited in the sense of automatic monitoring and remote sensing. The sample is analyzed in a lab where the determinations that can be performed are almost endless. For grab sampling, therefore, there has to be a decision made as to which parameters are to be measured and which are not. The decision must be based on the purpose of the sampling station (specific or trend data), the character of the stream, the waste discharged to the stream, the use of the stream's water, and the personnel and facilities available for surveillance. Also, the use to be made of the data must be considered in deciding which parameters are to be measured.

At one time or another, it is conceivable that almost every parameter measurable will be needed on a particular stream. It is impossible, however, to measure every parameter, and consequently, sound judgment must be used in making the final decision. This decision must relate to the particular situation associated with the sampling point. Again, however, it may not be very practical to have a different set of parameters to be measured at every sampling station. Some compromise must be developed with respect to the various situations that occur in a state.

Another very important aspect of parameter selection is public relations. This point was brought out very clearly by Brown and others (1970) in the following quote.

> "For more than twenty years, demands for billions of dollars of expenditures for water pollution control have been made on American municipalities and industires; but no provision has yet been made for keeping the public informed, in simple and understanable terms, as to what this effort and investment is achieving--or not achieving--in water quality enhancement."

Brown follows with the development of a water quality index which would help remedy the problem mentioned in the quote. For purposes of public relations, each sampling station that is sampled should have an index computed for that sample. If Brown's index is to be used, this would require the measurement of DO (in percent saturation), fecal coliform density (16/100 ml), pH, BOD_5 (mg/l), nitrate (mg/l), phosphate (mg/l), temperature (°C departure from equilibrium), turbidity (units), and total solids (mg/l). This then would be a standard set of parameters to be measured on every sample.

For Colorado, the proposed establishment of primary and secondary stations presents the opportunity to establish two general parameter sets with the index parameters serving as a basis of both. Each set would reflect the purpose of the station and, therefore, better meet the data needs of the agency. The secondary parameter set will be long, since the purpose is to establish trends of various water quality conditions. Each time the secondary stations are sampled and analyzed, the primary parameter list will also be analyzed since the primary list is a subset of the secondary list. This will establish trend data on many parameters at the primary stations. The primary parameter set, for practical reasons, cannot be too long since the number of samples will be large. The parameter set, however, needs to provide an indication of various aspects of water quality so that changing conditions can be noted and abatement action initiated.

Getting more specific, the secondary parameter set for Colorado should contain those parameters currently measured by the WPCD. Flow should also be included, but since its measurement may be performed by another agency (USGS, for example), some arrangements should be made to obtain the other agency's data. The list of secondary parameters is shown in Figure 25. The WPCD parameter set has evolved over the life of the agency and reflects the concern for existing water quality conditions in the state. This is not to say, however, that the list should be considered fixed; it should

Parameters

- Temperature
- Turbidity
- Conductivity
- Dissolved Oxygen
- Biochemical Oxygen Demand$_5$
- pH
- Total Volatile Residue
- Total Dissolved Solids
- Total Nonfiltrable Residue
- Total Settleable Residue
- Ammonia
- Nitrite
- Nitrate
- Phosphate
- Cyanide
- Total Hardness
- Calcium
- Magnesium
- Sodium
- Sodium Adsorption
- Chloride
- Sulfate
- Fluoride
- Arsenic
- Boron
- Cadmium
- Chromium
- Copper
- Iron
- Lead
- Manganese
- Silver
- Zinc
- Selenium
- Alpha Total
- Alpha-T Total
- Beta Total
- Beta-T Total
- Dissolved Radium 226
- Dissolved Radium 226 Counting Error
- Total Coliform
- Fecal Coliform
- Alkyl Benzene Sulfonate
- Mercury

Figure 25. Secondary parameter list for Colorado as reported from STORET.

remain flexible in order to reflect any changes that may occur.

For the primary parameter set, the list should contain parameter measurements which give indications of any physical, chemical, or biological quality changes. The parameters mentioned earlier for the water quality index, plus flow, would provide this basic information. And since the data is being gathered with a high frequency, it will give specific indications of a stream's water quality condition. Of course, the old argument of whether BOD should be included will arise, but regardless of the validity of the measurement, it is still considered by many to be very important as witnessed by its inclusion in the index. Questions will also arise concerning other parameters, but it must be remembered that this is a compromise.

In order to make the data more useful, several other bits of information need to be available. Time of sampling would be very useful in analyzing DO measurements and in developing general conclusions from the laboratory results. As mentioned above, flow data is needed to really make a quantitative analysis of pollution levels. Since Colorado is the highest state in the nation, elevation is a large factor in some of the parameter readings. The point in the stream where the sample was taken may be critical if complete dispersion of upstream wastes has not occurred. Other bits of information which may be useful are the sampler's name, technique of sampling (composite or single), field or lab analysis, how transported to the lab, and chemist's name. It is not necessary to store all of this in the data storage system. Instead, it may exist on the sample sheet which would follow the sample through the complete system and then be filed after the primary information was removed to be stored in a computer. The main point of this discussion is to emphasize the need for a logical, well-documented, and carefully executed procedure for collecting and analyzing water samples.

The parameter sets detailed above are to serve as the basic parameter lists for the samples. Adverse local situations may dictate that other parameters need to be measured at particular points. The sample sheet which follows the sample should provide a place for these additional samples, and any determinations different from the standard set should be decided on by the sample collector and noted on the sheet. This illustrates that the collection of samples is critical to obtaining descriptive information and, consequently, its importance should be emphasized.

Automatic Monitoring

As illustrated in Figure 23, automatic monitoring must be considered as an alternative to continued expansion of a grab sampling network in order to increase the effectiveness levels without pushing cost beyond reality. The ultimate, of course, would be to have automatic monitors at all 22 primary stations measuring the parameters technologically feasible and then to use grab sampling to supplement for the remaining parameters. This would increase the frequency of sampling by several magnitudes and would correspondingly increase the effectiveness levels nearer to 100 percent with respect to spill detection.

The parameter restrictions, discussed in the state-of-the-art paper, indicate that grab sampling must continue to be a part of the surveillance network. The importance of grab sampling, however, may be put on a secondary sampling basis providing the trend data, while the automatic monitors supply the enforcement data. The value of automatic monitoring data as enforcement data must be considered in deciding to rely completely upon it. This is especially true with respect to the parameter limitations and the ability of automatic monitoring data to stand up in court. This particular aspect has not been taken into consideration in the analysis to follow since the depend upon the stream characterization and the legal situation that will result when the data is first used in a court case. The final answer can only be obtained after the data has been presented in a local courtroom.

The truly major advantage of automatic monitoring over grab sampling is the real time nature of the technique. This permits immediate enforcement action to take place, but again, the problem arises as to how will this fact be expressed in a quantitative fashion. Agency action depends largely upon the agency personnel and the legal structure under which they operate. The action generated by the data acquisition technique can, therefore, not be considered within the analysis framework established in this report. The fact, however, remains that automatic monitoring provides a greater potential for faster abatement action than available through grab sampling for those parameters measured. The water quality manager must make his decisions with the above facts in mind.

The real basis in this report for comparison between automatic monitoring and grab sampling comes with respect to cost and spill detection. The 22 stations of the primary network in Colorado have automatic monitoring costs associated with them. The costs are original equipment purchase and operation and maintenance. In the state-of-the-art paper, these costs have been reviewed, but specific costs for specific situations will of course be different. For the costs quoted below, average figures have been used.

The cost of installing and operating automatic monitors at all 22 of Colorado's primary stations will be used to compare the technique with grab sampling. The purpose of the primary network is enforcement, and this is where automatic monitoring has its advantages. The effectiveness levels (spill detection) using automatic monitoring will be close to 100 percent; therefore, the question breaks down to one of cost. By determining the total cost involved for automatic monitors, the trade offs between cost and effectiveness can be visualized.

The average of the total yearly costs presented in the automatic monitoring state-of-the-art paper is $5,930. For the 22 primary stations in Colorado, this results in an annual cost of $130,460. Referring back to Figure 23, this would buy an effectiveness level of approximately 43 percent using grab sampling. With automatic monitoring, the levels of effectiveness are much closer to 100 percent for the prarmeters measured. This indicates that Colorado, for purposes of abatement and enforcement, would be getting more information for the money if automatic monitoring was to be used. Of course this must be tempered with a waste constituent analysis in order to determine if automatic monitors can detect a majority of the wastes emitted.

Another extremely important factor in the above analysis is the initial costs involved. The above figures are a result of a long-term view. To implement the 22 automatic monitors would require an initial investment of $176,000 with strip chart recorders. Again, this is based on an average figure of $8,000 per unit obtained from the state-of-the-art paper on automatic monitoring. However, strip chart recording removes one of the big advantages of automatic monitoring--real time data. With a telemetry system and a data logging device, the initial cost per unit goes to $12,000 for a total initial cost of $264,000. The use of computers pushes the initial costs up even higher.

Considering the high initial costs, the establishment of a complete automatic monitor network must be considered on the basis of installing a certain number (exact number established by budget consideration) each year. The effort (money and manpower) devoted to the automatic monitor network must not, however, detract from the secondary network which is also very important in providing data on all parameters.

The comparisons just made must be considered in the light of the assumptions necessary to arrive at the figures. The primary grab sampling network is sampling more parameters than an automatic monitor is capable of. Consequently, the spill detection of automatic monitors must be considered in light of the limited parameters. Also, the cost of grab sampling includes these extra parameter determinations. The figures quoted for automatic monitoring are average figures derived from the literature, and specific costs at specific geographic locations may vary greatly. Also, many of the dollar figures quoted in the state-of-the-art paper are subject to increases due to inflation, etc. This is especially true with some of the earlier articles. For a more detailed analysis of the cost-effectiveness for automatic monitoring, refer to Sylvester (1972).

Remote Sensing

Remote sensing, as a quantitative data acquisition technique, is the least comparable of the three techniques considered. This was brought out very clearly in the state-of-the-art paper when the comparison was made between sight and the other, more quantitative, senses. However, some rough analyses can be performed to supply the water quality manager with an understanding of where remote sensing may fit into his overall program.

The first and major advantage of remote sensing is the spatial coverage of surveillance. This can be envisioned as an almost infinite number of sampling stations on the streams to be photographed. The sampling frequency can be as often as desirable, realizing however that the cost of sampling will be high. The parameters which can be measured from each sample depend heavily upon the equipment used. For this reason, remote sensing surveillance is used more for studying a specific element or elements than for routinely flying over an area and looking for whatever may be causing a water pollution problem.

In order to perform a cost-effectiveness analysis, however, it will be assumed that the remote sensor can detect pollution events on a routine flight basis. Also, for purposes of analysis, it will be assumed that equipment similar to that at Colorado State University (CSU) is utilized. (CSU's equipment is listed in the remote sensing state-of-the-art paper.) It costs approximately $200/day to use this equipment. The plane costs $100/hr, and the operator is paid $100/day. The plane flies at an average 200 miles per hour. Flying at 2000 feet with 60 percent overlap, it will take approximately five pictures to cover each mile. Film, processing, and interpretation cost around $10 per picture.

Colorado has 14,503 miles of streams within its boundaries. Of this total, it will be assumed that only the main stems and major tributaries will be routinely surveyed by the remote sensing equipment. This will be estimated at 3600 miles or a total of 18 hours of air time per routine sample. Eighteen hours of operation will involve a cost of $2400. The mileage (3600 miles) will require, for pictures, a cost of $180,000. It can immediately be seen that this cost is beyond reality for routine sampling. For a special survey of the entire state, this figure may be more practical.

In order to create a cost-effective analysis, assume that only 100 miles are to be surveyed routinely. These would be the more polluted rivers of the state and the different reaches will probably be in different parts of the state. This will involve using the equipment for one-half day or a cost of $550. For 100 miles, 500 pictures will be needed for a cost of $5,000. Thus, each routine remote sensing sample would cost $5,550. Sampling monthly would require an annual cost of $66,600 for only 100 miles of stream.

If the remote sensor detects every pollution event at the time of the picture, the detection percentage can be approximated by dividing the number of events noted by the number that occur during the month. Theoretically, if 3000 events occur during a month (100 each day) and their duration is between 0 and 3 days, at most 300 events could be detected. This yields a percentage of 10 percent.

Comparing the effectiveness percent of 10 percent with the cost of $66,600, indicates that for a routine basis, remote sensing is expensive. For $66,600, grab sampling is better than 20 percent effective, and this is for the entire state, not just 100 miles of streams. Also, the 10 percent detection may be high when it is considered that remote sensing cannot detect every pollutant.

The above discussion indicates that remote sensing is very expensive if it is to be used in the surveillance of water quality on a routine basis. The cost, therefore, tends to preclude the use of remote sensing for routine water quality surveillance. However, the spatial coverage gained through its use would indicate a distinct advantage in special surveys or inventory work. The information gained in this case would be worth the cost. Given that remote sensing is not practical on a routine basis, the question becomes, how would remote sensing fit into a state program such that its spatial advantage could be utilized.

As noted earlier in the report, the design of a routine surveillance network id dependent upon adequate information on stream characteristics and an inventory of existing waste loading and water use conditions. Since remote sensing can speed the acquisition of this information, its major contribution to a state agency will be in the area of special surveys which would then be used to optimize the development of routine surveillance. This implies that remote sensing, with its great spatial coverage, would serve to help identify problems, while the other two techniques would then be used to selectively quantify the situation.

A perfect example of this for Colorado is the identification of acid mine drainage areas. Once the sources were identified, an action program could be started concentrating on the worst offenders first. The program would entail more refinement in the evidence through more quantitative analyses, but the inventory of the problem would have been greatly simplified.

Before actually discussing the use of remote sensing, the reliability of the results must be assured. The state-of-the-art paper indicated the great care needed in using remote sensing if reliable results are to be obtained. The survey must be well planned and well executed relative to agencial goals if the inventory is to supply the data sought.

Considering the facts presented above, it must be concluded that remote sensing would not be practical for Colorado in its routine surveillance efforts. The decision of whether or not to use remote sensing in special surveys must depend upon an evaluation of the type of data needed for the survey, an analysis of the ability of remote sensing to supply the needed data, and the ability to get the data at a cost that can be tolerated by the agency involved.

SECTION IX

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SECTION X

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SECTION XI

APPENDICES

Page

A. Grab Sampling: State-of-the-Art 131

B. Automatic Monitoring: State-of-the-Art 149

C. Remote Sensing: State-of-the-Art 191

D. Colorado's Stream Characterizations 225

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APPENDIX A

GRAB SAMPLING: STATE-OF-THE-ART

Grab sampling has traditionally been the sampling technique used in water quality management. Grab sampling is a term used to describe the process of going to a specified, spot on a stream, removing a sample of water (grab sample), carrying the sample back to a laboratory and performing tests on the sample in order to determine the values of various parameters used to quantify water quality. Since the sample is analyzed in a laboratory, there is essentially an unlimited number of parameters which may be measured.

As noted in Section VI, there are many articles in the literature concerning data acquisition in general while there are few relating specifically to grab sampling. Since these general articles do include grab sampling, they are reviewed in the grab sampling section and are not repeated in the automatic monitoring or remote sensing state-of-the-art papers.

The following discussion is concerned primarily with routine water quality surveillance data acquisition; however, it is recognized that many other data types (special surveys, waste inventories, etc.) are necessary for the successful operation of a water quality management organization.

Functional Data Needs

There are many ways in which a water quality management organization can be divided by functions. Seven functional objectives were listed at the beginning of this report. McDermott (1968) states that water quality monitoring is a support activity for three functions: (1) water quality standards enforcement and revision; (2) water quality baseline and trend evaluation; and (3) planning and management programs. DeFalco (1964) classifies data needs as follows:

1. To determine compliance with a given standard
2. To determine or forecast the effect of a water resource project
3. To determine treatment needs in the use of the water
4. To provide water quality control.

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How the purposes are grouped is not important. To realize, however, that the data required varies greatly with the purpose of collection is important. This should be considered in designing a quality surveillance system. Some of the general problems encountered in surveillance system planning are discussed by Pomeroy and Orlob (1967). They state that minimum data needs are dependent upon drainage area, length of water course, slope, surveillance cycle, and pollution characteristics, along with other factors. Sayers (1971) discusses data needs from water quality surveillance. He notes that there are two ways to obtain the data: 1) through a vast network of strategically located long-term stations, or 2) through use of repeated short-term surveys. A combination of the two can supply the most efficient source of data. Gannon and Wezernak (1967) say that water quality information should be collected with a definite purpose in mind.

Moody (1970) has described the data requirements for planning purposes. These are primarily data for evaluating base level stream quality conditions and quality trends and for identifying problem areas. These data are usually then incorporated into a planning model to aid in the decision-making process. Moody points out errors in the data itself, or in its analysis, may cause over or under design and result in loss of economic efficiency for a project. Petri (1970) notes that planning data is often insufficient for several reasons, one of which is that data needs are not anticipated far enough in advance. Anderson, et al (1968) points out the lack of water quality trend analysis in the literature and blames this primarily on a lack of reliable and extensive data of sufficient time length. Allen (1971) states that no general procedures for the establishment of a satisfactory sampling program applicable to all situations can be stated.

Data collected under a routine surveillance program may indicate areas where additional study or research is necessary. Research may then be performed by the agency concerned, or contracted outside. As noted above, this point was brought out by Sayers (1971).

With respect to data needs for design purposes, Bramer (1970) notes that since treatment facilities are installed to maintain water quality levels in streams, the basic water quality data requirements are concerned with the nature of the receiving stream and the applicable water quality criteria. These requirements are used to establish effluent requirements and evaluate the proposed treatment facility. Receiving stream data requirements will vary greatly with the stream characteristics and the water usage, according to Bramer.

In order to supply data needed for stream standard enforcement, a surveillance system must have a high probability of detecting stream standard violations. If enforcement of stream standards results in court action, the data must prove that violations have occurred and the source responsible. Ballinger (1967) indicates that the methods used and the quality control employed are quite important in obtaining data which will withstand vigorous challenges during legal proceedings. An intensive water quality survey with strict quality control measures is necessary to obtain data which will meet these requirements.

Parameter Measurement

McDermott (1968) states that if the primary purpose of data collection is to determine standards compliance, then the quality parameters listed in the standards should be given primary consideration in a surveillance system. In most instances, the parameters listed in the standards are far fewer than those available. McDermott has summarized the frequency of parameter usage in state standards. He indicates that only nine of the many available parameters appear in the standards of all states.

Five of the nine parameters appearing in state stream standards are termed the "Five Freedoms:" freedom from the presence of floating solids, settleable solids, unnatural turbidity or color, unnatural taste or odor, and toxic substances. The other four are DO, ppH, coliforms, and temperature. McDermott notes that the first four freedoms require use of man's senses and judgment as opposed to determination by analytical methods solely. Morgan (1970) discusses parameters of interest for basic water quality data, particularly with respect to water usage. He indicates that selection of parameters for monitoring should be on this basis.

If long term base level data is the data collection purpose, it is desirable to measure a wide range of parameters, according to McDermott (1968). Parameters not presently included in water quality standards may be added to standards at some later date, or may be needed for current or future planning purposes. McDermott lists seventy parameters which may be used to quantify stream water qualtiy. Of these, all but four are listed in Standard Methods (1965) and can be determined using grab sampling and traditional wet chemistry methods. Obviously, grab sampling has a capability of almost one hundred percent with regard to parameter measurement. Ballinger (1967) indicates that only those procedures listed in Standard Methods have been acceptable for obtaining data for use in legal proceedings, so far. This implies that intensive surveillance using grab sampling methods is necessary for obtaining legally acceptable data.

Several studies have been conducted on the use of index parameters for water quality surveillance. The primary purpose of using such indexes is the possible reduction of sample analyses necessary to obtain the needed data. In addition, index parameters may be useful in estimation of missing data points and in determining sampling schedules. Wang and Evans (1970) used regression analysis and found good relationships using streamflow as the independent variable and various nutrient concentrations as dependent variables. Durum (1953) also used streamflow as the independent, or index, variable with mineral concentrations as the dependent variables. Gunnerson (1967) tried both streamflow and TDS as indicator variables on a Columbia River study with fairly good success. Steele (1969) used both streamflow and specific conductance as independent variables with various ionic constituents as dependent variables. He found specific conductance to be the best indicator parameter. Notably, all of these studies have selected a parameter for the independent variable which is easily measured and for which long term records are commonly available.

Sampling Frequency

The frequency of sampling necessary to obtain data satisfactory for its intended purpose is difficult to define. Kittrell (1969) says frequency of sampling varies with water use, the urgency of developing a representative record of quality, and the capacity of the responsible agency for sample collection and analysis. He points out that due to logistics, control agencies often sample at monthly or longer intervals, thereby allowing many standard violations to occur without being detected because of such infrequent sampling. Kittrell questions the practice of routine monitoring at regular intervals throughout the year and suggests greater economy might be achieved by limiting the sampling to periods of potential damage. Allen (1971) agrees with Kittrell in that the number of samples required to describe a natural water depends on the variability of the constituent to be analyzed. Allen also notes that too frequently the samples are divided among too many stations. The collection of more samples and fewer stations permits statistical analysis of the data with much more reliable results. Deininger (1971) discusses the "statistics" of water quality surveillance.

Stream water quality may exhibit diurnal, seasonal, annual, or other cyclic patterns (Fair, et al, 1968). In addition, it also will show random variation from meteorological and hydrological events. Pollution occurrences may be random or cyclic in nature. An example of a cyclic type might be the effluent discharge from a seasonal industry such as food processing. An accidental pollutant spill would more likely fall into a random uniform pattern.

A California study (Gunnerson, 1962) points out that grab sampling will miss, or detect, pollution events by chance. Quality of an individual stream may range from highly variable to fairly stable depending upon local hydrologic and meteorologic conditions, the nature of the stream itself, and the contributing pollution sources. McDermott (1968) states that the variability of the stream quality dictates to a large extent the frequency of sampling necessary to characterize the stream. In designing a surveillance system, it is desirable to use the minimum sampling frequency which will supply the necessary information. In an Ontario study, Rizvi (1969) used analysis of variance on historical lake water quality data to determine minimum sampling frequencies. Since lake conditions were relatively stable, he found that previous sampling frequencies could often be significantly reduced with no loss of information. Gunnerson (1966) employed power spectra analysis to determine optimum sampling frequency for DO and specific conductance in a tidal estuary. He noted that for study of periodic harmonic motion, observations must be at less than one-half the wave period. His studies showed that the optimum sampling frequency for the parameters studied was about two hours. Moody (1970) also discusses the use of power spectra analysis for determining sampling frequency. Thomann (1967) used time series analysis to study the periodicity of DO and temperature in an Delaware estuary. All of these studies have been concerned with short term periodic variation (e.g., diurnal) for which very frequent observations are necessary. Obviously, routine surveillance by grab sampling is impractical for this purpose.

Steele (1970) investigated the effects of sampling frequency using regression analysis. He simulated short term quality variations by use of their relations to index variables as described earlier. The simulated data was then compared to observed data. He notes that time-dependent variations may be masked by this method.

Pomeroy and Orlob (1967) present minimum surveillance requirements for streams. They recommend the minimum numbers of stations and sampling frequencies for given situations based primarily on stream slopes and flow variability. They do not explain how these recommended numbers were obtained. Weisbecker, et al (1970) propose a methodology for planning monitoring programs assuming that preliminary data such as water usage, base level quality and important parameter data are available. They recommend sampling frequencies for various parameters based on the variation expected and the importance of the parameter.

Sampling Station Locations

Sample site selection is, in most cases, somewhat arbitrary. Sites should be located at the most representative points, according to Ball (1970). Kittrell (1969) states that sites should account for present and potential pollution sources, water usage, and physical stream characteristics. Kittrell and West (1967) emphasize that stations should be located to obtain the most representative data, rather than for convenience. A general discussion on representative sampling is given by Roskopf (1968), who states that there is no ideal time and place for sampling for all purposes. Velz (1950) discusses several factors to consider in station location. He notes that stations should not be located immediately below tributary mouths, or pollution sources. Colorado stations are based on water quality standard change points, among other considerations (Misbach, 1971). At least one study has been conducted using statistical techniques to analyze station locations. Palmer and Sato (1968) used multiple and pair testing on data from lake sampling stations in Ontario to test similarity between station results. They found that stations could be reduced to prevent duplication of data and increase efficiency. McDermott (1968) feels that a minimum of sampling stations with a high sampling frequency will provide the best data. He also states that the adequacy of a sampling schedule should be judged by the ninety-five percent confidence interval for correctly defining the stream quality. Obviously, a very high sampling frequency would be necessary to meet this criterion.

General Surveillance Design Studies

A few authors have described general procedures for design of water quality surveillance systems. Roche (1970) emphasizes the need for cooperative effort among concerned agencies to achieve an effective monitoring program. Kittrell (1969) discusses general guidelines for establishing a surveillance system. Haney and Schmidt (1958) point out the importance of proper planning and present several points to be considered in sampling program design.

Recommendations were made regarding a complete surveillance system for the Sacramento River in a California study (Gunnerson, 1962) but the basis for some of the recommendations, such as sampling frequencies, was not made clear. A systems analysis approach was used in a study conducted for FWQA (1970). The objective of this study was to develop a general method for the design of surveillance systems for major river basins. The selection of parameters to be measured was primarily based on the capabilities of automatic monitors and on stream standards at the particular points sampled. A sampling frequency of once or twice monthly, depending upon location, was recommended for those parameters not continuously monitored. The report states that these frequencies are based on the needs to protect water uses, as well as to provide information necessary for future evaluation. However, the report does not explain how the sampling frequencies were selected on this basis. Surveillance stations were located on the basis of their relation to (1) interstate borders, (2) potable water supplies of major population centers, (3) major pollution sources, and (4) tributary streams.

Several papers describe and recommend increased use of the STORET system for data handling and retrieval. A basic description of the system and its use is found in a publication published by FWPCA (1966). Taylor (1970) has explained some of the STORET characteristics and mentions some experiences with its use.

Sampling Procedures

As noted earlier, the design of a grab sampling surveillance network involves a determination of station location, frequency of sampling and parameters of consequence. Once the above design criteria are established, implementation becomes a crucial factor. Implementation involves the establishment of sampling routes, field measurement of certain parameters, sample collection techniques, sample preservation and storage techniques, and shipping procedures to assure rapid laboratory analysis of the sample. In general, these can be referred to as sampling procedures.

Kittrell (1969) in the preface to his guide to water quality surveys, notes that Standard Methods (1965), a 769-page volume, has been prepared to guide the analysis and examination of water samples, but that there is very little published information which can be used to guide the acquisition of samples that represent stream conditions. He indicates that the variability that exists from stream to stream may be the major reason for this. Kittrell hopes that his discussion of the subject will help fill this need.

Although Standard Methods (1971) is concerned mainly with analysis and examination of water samples, it does very briefly discuss sampling procedures. Rather than repeat all the facts here, just some high points will be noted. In the actual sampling, no attempt should be made to use the same sample for chemical, bacteriologic, and microscopic examinations. The methods of collection and handling are too different to permit this. Standard Methods (1971) reviews the differences at the beginning of each major section and then notes particular aspects of sampling and storage associated with each parameter in that section.

In general, the laboratory analysis of a sample will be more reliable for those samples that have the shorter time elapse between collection and analysis. No hard and fast times may be stated as to time elapse and effect on the sample. The effect depends upon the character of the sample, the particular analysis, and the conditions of storage. Standard Methods (1971) suggests the following as maximum limits for samples for physical and chemical analysis:

Unpolluted Waters	72 hours
Slightly Polluted Waters	48 hours
Polluted Waters	12 hours

For bacteriological examinations, it is recommended that samples be analyzed within one hour of collection. If this is not possible, the sample should be iced and in transport for not more than six hours. If times are greater than this, alternatives should be considered. In all cases the time elapsed between sample collection and sample analysis should be recorded.

Certain constituents and physical values require field analysis in order to obtain accurate results. Dissolved gases (oxygen, carbon dioxide) may be gained or lost; temperature can change rapidly; pH may change significantly in a few minutes. Because of this, these parameters must be measured in the field. There is a developing technology revolving around portable meters for measuring pH, temperature, dissolved oxygen, specific conductance, etc. Scott (1964) discusses the development of an instrument to read dissolved oxygen. Just six years later, Stack (1970) indicates that measurements of water quality have been greatly facilitated by portable instrumentation. He bemoans the fact that there is no compact multiparameter kit to make field measurements much easier. He, therefore, proposes and presents a multiparameter kit but indicates that the design of such a system should include careful evaluation of prarmeters to be measured and the accuracy required for various uses of the data.

Ficken (1970) presents a state-of-the-art paper on sensors used to measure electrical conductivity, temperature, dissolved oxygen, pH, turbidity, and specific ions. He notes that considerable time is spent cleaning and checking calibration of sensors. Mancy (1971) also gives a very thorough discussion of sensors and instrumentation.

Grab sampling usually refers to the obtaining of a sample at a single point in space and time. Various references (Kittrell, 1969; Roskopf, 1968; USGS, 1960) describe procedures such as the compositing of samples and the use of depth integrating samplers to obtain more representative samples. Ball (1970) discusses errors to avoid in sample collection. Among these are errors in site selection, sample collection and field measurements, and sample preservation and storage. He describes a cross sectional sampling procedure used by the Bureau of Reclamation for determining the most representative sampling sites.

Haney and Schmidt (1958) and Velz (1950) both elaborate on representative sampling. They mention the importance of understanding the major factors that affect stream sampling before one converts a survey strategy into a tactical plan of implementation. The major factors are: 1) sampling as related to the daily hydrograph, 2) sampling in relation to sources of pollution and tributaries, 3) sampling in relation to physical characteristics and river developments, 4) sampling in relation to waste discharge, and 5) abnormalities in natural purification.

Haney and Schmidt (1968) also mention that composite sampling has its greatest usefulness in connection with correlative studies of pollution loads. They also note that composite samples automatically mask quality abnormalities in the stream being sampled. It is often these variations that are of importance. Tarazi and others

(1970) discuss the advantages and disadvantages of automatically obtaining daily composite samples of flow-proportioned aliquots from a stream. They also discuss a second technique which consists of automatically taking three grab samples daily.

If samples cannot be analyzed within the prescribed maximum time limits, it will be necessary to utilize preservatives and adequate storage conditions. Standard Methods (1971) and FWPCA (1969) both give instructions for preservation and storage of samples for particular unstable constituents. Kittrell (1969) notes that much research is needed to develop the most reliable preservation methods for many constituents. Schaumburg (1971) discusses a new concept in sample preservation--poisoning and depoisoning.

For more concentrated studies, there is an assortment of sampling equipment available. There are automatic composite samplers and automatic grab samplers, both refrigerated and non-refrigerated. For routine grab sampling surveillance where only one sample per month is collected, there is little need for this equipment. For the manual collection of one grab sample, there is equipment available. Both Standard Methods (1971) and Kittrell (1969) describe special devices to collect a sample for DO determinations. They describe an Ohio-type sampler and the Juday bottle (and some of its modifications, the Kemmerer or Van Dorn). These devices also may be used to collect samples for other determinations.

In the collection of any sample, the knowledge, skill, and concern of the collector is crucial. Kittrell (1969) also emphasizes the point that the person analyzing the data and making interpretations from the data should also be familiar with the sampling locations and procedures. There is very little published information relating to manpower requirements for a routine grab sampling network. The manpower level would depend upon the surveillance effort and design. FWQA (1970) presents the manpower levels of all the state agencies. One of the classifications is pollution control surveillance and enforcement.

Estuary Sampling

Estuaries present very complex problems in terms of water quality. Their hydrologic and hydrodynamic characteristics are complex and the mixing of fresh and saline waters compounds this complexity. Considering that many estuary shores are industrial centers producing a wide variety of pollutants, one sees that the problems can become enormous.

The Delaware River Estuary has been the subject of considerable study. O'Connor, et al (1968) indicate that several agencies sample this estuary regularly, but give no background as to the planning of the sampling program. Thomann (1967) used data from the Delaware River Estuary in his study of time series analysis of water quality data.

The problems involved in estuary water quality surveillance are discussed by Pomeroy and Orlob (1967). Among the factors they state should be considered are: 1) type of quality constituent; 2) size of estuary; 3) shape of estuary; 4) relation between runoff, tidal action, and mixing potential; 5) degree of stratification; 6) quality, hydrologic, and hydrodynamic cycles; and 7) periodic versus random phenomena. They present a set of minimum surveillance requirements for various types of estuaries. These recommendations are based on what the authors term the minimum surveillance to obtain statistically significant data. They do not, however, describe any of the methods used to arrive at these numbers, other than to state that at least six samples per cycle are necessary to characterize a periodic phenomenon.

Gunnerson (1966) used time series analysis to determine optimum sampling intervals in tidal estuaries. His study was primarily concerned with short term periodic phenomena, although the method can be applied to any time period for which adequate data is available. The use of spectral analysis for analyzing water quality data from streams and estuaries is described by Wastler (1963).

Gibbs and Isaac (1968) discuss the water quality monitoring program for the Duwamish Estuary near Seattle, Washington. They state that manual sampling was considered impractical in this situation due to complexities of the estuary system. They also note that manual sampling is used for parameters not available from automatic monitors.

Velz (1950) notes that the semi-daily tidal cycle is a major factor controlling estuary quality, necessitating sampling at frequent intervals (one to two hours). He states that the tidal influence tends to prevent sudden changes in water quality but that random sampling is of little value. Therefore, frequent, controlled sampling is required to properly define estuary quality conditions.

Costs

Costs of water quality data collection vary with the methods used and with locale, but it is generally accepted that costs are high. Petri (1970) states that one of the basic reasons for insufficient planning data, in many instances, is the high cost of sample collection, laboratory analysis, and data reporting. Gunnerson (1962) feels that four man-days of handling and evaluation are needed for every one man-day of data collection, not including laboratory requirements. De Falco (1964) gives the cost of manual surveillance as $25 to $50 for sample collection and the same for laboratory analysis. ORSANCO records (Klein, et al, 1968) indicate that the cost of manual sampling and analysis in that area is about $2.20 per data item. Since the term "data item" is not defined by Klein, it is assumed to be the value of one parameter from one sample. Maylath (1970) states that the costs for manual sampling and analysis in New York State are about $6.00 per parameter value. The term "parameter value" is assumed to be the same as "data item" used above.

Manual sampling is the only method used presently in Colorado for routine quality monitoring. The actual costs for this program in Colorado during the 1970-71 fiscal year were assembled by Misbach (1971) and used to calculate costs per sample. His figures show these values: sample collection, $21.40 per sample; chemical, bacteriological, and radiological analyses, $34.80 per sample; data handling and analysis, $10.18 per sample. These total up to a cost of $66.38 per sample. The Colorado Water Pollution Control Division shares laboratory facilities with the state Public Health Department and contributes an amount of financial support proportional to the work load due to analysis of water samples. This includes equipment costs. For this reason, Misbach (1971) indicates that laboratory analysis costs were based on their contribution rather than actual compilation of laboratory costs.

There is not enough information given on the basis of these costs for routine surveillance to allow direct comparison, or to give reasons for the variation. The point is made by almost all authors that due to the high costs involved, proper planning of surveillance systems is very important.

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APPENDIX B

AUTOMATIC MONITORING: STATE-OF-THE-ART

A concise definition of automatic monitoring is, "continuous multiparameter measurement of water quality characteristics" (Ballinger, 1968). The design specifications of systems fulfilling the above requirements are described by Mentink (1968). In general, such a system requires three functional modules: 1) flow chamber; 2) analyzer; and 3) output component.

Immersion monitors do not require a flow chamber as analyzer and output components are submerged in the water body being sampled. For the same reason, support equipment (shelter and pump) is also not necessary.

Support equipment is necessary unless an immersion monitor is employed. Usually a shelter is needed to house the monitor and provide environmental protection. Also, a positive displacement submersible pump is required(A Program Guide to Automated Instrumentation for Water Pollution Surveillance, 1966).

Operation of a system entails sample collection by submersible pump and intake line, analysis by parametric sensors located in the flow chamber, signal conditioning in the analyzer phase, and data recording and/or transmission in the output module (Cleary, 1967, pp 201-202).

A fair amount of flexibility is allowed in the choice of recording mode. The methods available include on-site strip chart recording, punched paper tape, or magnetic tape (Smoot, 1970; Anderson, 1970). Recording format can be either analog or digital (Mentink, 1968). When telemetry is employed, output devices are located at a central receiving station containing the computer. The same choice of recording mode is available except that here it is advisable to perform teletype log sheet display in addition to other data logging. Thus, rapid detection of water quality changes as well as data storage for later statistical analyses is provided (A Program Guide to Automated Instrumentation for Water Pollution Surveillance, 1966).

Telemetry requires transmitter components, communications link, interface, computer, and output devices (Anderson, 1970; Metink, 1966). The transmitter module is composed of a programmer which sequences sensor recording, an input addressor which assigns sensor signals to the appropriate

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memory storage module, and an output addressor which calls for transmission of values contained in the memory storage modules. The communications link may be telegraph, radio, microwave or a combination of these (Smoot, 1970). The interface contains the receiver which accepts signals from the monitors and converts these for display or recording (Anderson, 1970; Metink, 1966). For a discussion of the computer facilities available, see Anderson (1970) and Burroughs Corporation Product Brochures on electronic data processing systems.

Like data recording, telemetry may employ either analog or digital formats for data transmission (Shubrooks, 1968). Also, a telemetry system may be adapted for simultaneous two-way communication (duplexing) (Smoot, 1970). Two-way communications allow functional commands (pump and automatic sampler activation, A.C. power control, etc.) to be sent to the monitor from a central receiving station. Thus, computer control over the operation of the entire telemetry and monitoring network is possible (Anderson, 1970).

There are two approaches to continuous measurement of water quality characteristics. One employs electro-chemical probe type sensors while the other utilizes automated wet-chemical analyses (Ballinger, 1968; Jones & Joyce, 1960). For a discussion on the basics of operation of electrochemical probes, see Ficken (1970).

Most of the following discussion on the application of automatic monitoring systems will be restricted to electrochemical probe type monitors because present wet-chemical monitors are not suitable for field use requiring unattemded operation (O'Brien & Olson, 1970; Ballinger, Personal Communication, 1971; Maylath, 1970).

Historical Review of the Use of Automatic Instrumentation for Water Pollution Control

The following discussion on the application of automatic monitors is divided according to level of government. The federal, interstate, and state applications have been aimed primarily toward stream or estuary surveillance while the municipal applications have centered around influent and effluent monitoring. Accordingly, the discussion of the various types of automatic monitors is broken down by application. If the reader is interested in effluent monitoring only, the discussion can be found under municipal applications.

Development of Instrumentation

Initial development of automatic monitoring instrumentation was undertaken by various industries to provide a means of process control (Marks, 1966). Beginning in the mid-1940's with the introduction of the laboratory pH meter for on-line use, many laboratory instruments have been adapted for process stream monitoring (Considine, 1965). A list of available process stream monitors and their application in various industries is given by Kehoe (1965).

Federal Applications

Actual field use of automatic instrumentation did not take place until the mid-1950's. Much of the initial work on the application of automatic monitors to measure water quality characteristics was performed by the U.S. Geological Survey (USGS). Initial systems applied in 1955 were only capable of measuring one or two water quality characteristics: conductivity and/or water temperature. Strip chart recording was standard which required manual extraction of the data. Because this process was very time consuming and costly, conversion to punch paper tape and/or telemetry was commenced in 1965. Both methods have the advantage that recorded data is computer compatible; that is, data recorded is ready for computer processing without prior manual manipulation. Most of the some 300 automatic monitoring stations now operated by the USGS employ this preferred type of data recording (Blakey, 1970).

One of the first applications by the USGS of automatic monitors was made on the Delaware Estuary. In 1955, conductivity recorders were employed to aid in a study of salinity fluctuations in the estuary. Because of the rapid fluctuations in other water quality characteristics besides salinity, temperature, pH, DO, and turbidity recorders were later added. Eventually, an automatic monitoring network was set up corresponding to the already established grab sampling system (McCartney & Beamer, 1962). The automatic system was only meant to supplement monthly grab sampling, but it was assumed that the monitor data would be useful for detecting and alerting downstream users of the occurrence of accidental spills. Also, it was hoped that the automatic data could be used for predicting future water quality trends and for more effective checking and evaluating of municipal and industrial waste control efforts (Anon., Wastes Engineering, 1961).

In 1963, attempts were made to improve on this system by evaluating an electronic "Sentinel" analyzer manufactured by Honeywell. Results of tests were favorable and indicated that the "Sentinel" was reliable and relatively trouble-free (Keyser, 1964). Similar results were claimed by Honeywell by testing a "Sentinel" unit on the Schuylkill River, tributary to the Delaware (Anon, Chemistry and Engineering News, 1963). Advantages of the Honeywell monitor were that the pH, DO, T, cond, and turbidity sensors were all contained in one cabinet, two new sensors were added, air temperature and solar radiation, and punched paper tape recording was possible. Further testing resulted in improving the "Sentinel" until it was capable of measuring chlorides, oxidation reduction potential, stage, and wind direction in addition to the before-mentioned parameters (Keyser, 1964).

Another early USGS installation was located on the Patuxent River Estuary in Maryland. In 1963, a Honeywell "Sentinel" was installed here to help determine the effects thermal pollution might have on the biological life of the estuary. Because of the comprehensive nature of the investigation requiring a large number of samples over 24-hour periods, automatic monitoring was considered of primary importance for water quality data acquisition. Rapid and variable fluctuations in water quality required temperature profiles and continuous measurement by conductivity, DO, temperature, turbidity, stage and wind speed and direction (Cory & Davis, 1965). The grab sampling program was not scrapped and proved beneficial because of the correlation of automatic data with spot samples taken elsewhere in the estuary (Nauman & Cory, 1970). Since only one "Sentinel" was employed, location was very important. Thus, the monitor was installed at the center pier of Benedict Bridge in a small laboratory. Since a continuous record of water quality data was required, strip chart recording was chosen (Cory & Davis, 1965). A good account of the operating experience, reliability of data, and cost of this automatic system for a six-year period from 1963-1969 is given by Nauman and Cory (1970).

Other agencies within the Department of Interior have also been interest in automatic water quality surveillance. The Environmental Protection Agency (EPA) has made extensive use of automatic monitors. As of 1969, it had 56 automatic water quality data acquisition systems in use (McDermott, Ballinger, and Sayers, 1968).

The Potomac system is one of EPA's biggest ventures in automatic monitoring. Data necessary to develop and verify a mathematical model of the Potomac River and Estuary could not be supplied except by the use of automatic monitors. Thus, an integrated automatic system consisting of four stations was established. Data on DO, temperature, and chlorides required by the model was telemetered to EPA headquarters in Washington, D.C. By testing alternate programs for water pollution control, the model will be helpful in Potomac water quality management (McDermott, Ballinger, and Sayers, 1968).

EPA has also operated an automatic system in the New York Harbor area since 1963. Monitoring is performed to obtain a historical record on the water quality of the Raritan River and Estuary. The Hudson-Delaware Basins Office, EPA feels this data will be necessary for water quality models of the estuary (Bromberg & Carames, 1970).

The historical record was originally provided by a network of four monitoring stations. A fifth station was added in 1969. All stations measure pH, conductivity, temperature, and DO. Some also measure turbidity, ORP and/or solar radiation, as well as wind velocity and direction. On-site punched paper tape was initially employed to record the data. However, due to poor performance resulting in over 50 percent loss of usable record, a telemetry system was installed in 1967.

Experience with the telemetry system has been much more favorable with a 91 percent usuable record obtained. Teletype is used to transmit data from the monitors to the central receiving station where data is displayed on typewritten log sheets and recorded on punched paper tape. Daily statistical summaries are preapred from the punched paper tape and then data from the punched paper tape is transferred to magnetic tape for storage and future analyses. Since samples are analyzed from three depths, data retrieval is fairly complicated. A complete interrogation of each station takes 45 minutes with values from one level being transferred every 15 minutes.

Operation of an automatic monitoring network in an estuarine environment was particularly difficult due to additional maintenance problems produced by increased salinity. Tri-level sampling, although possibly valuable for obtaining a more representative picture of estuarine water quality, produced additional maintenance problems because three submersible pumps and a valve network were required at each station to keep samples separate. Pumps and valve manifolds had to be rebuilt or replaced every three months due to salt water corrosion. Shelters housing monitors suffered a similar corrosion and had to be replaced every three years. In addition, salt bridging on monitor sensors produced a greater than normal electrical-mechanical drift. Hence, routine washing with distilled water and increasing the distance between sensors and their electrical connections were executed. To perform the necessary servicing a maintenance crew of three technicians was required (Bromberg & Carames, 1970).

Mobile monitors have also been employed by the EPA to survey water quality. A mobile laboratory used in the Hudson-Delaware Basin was designed with the capability of operating monitors in remote locations. Either probe or wet-chemical type analyzers can be incorporated into the lab. Since this laboratory was designed with multi-utility in mind, monitoring equipment is not always carried. When sucn instrumentation is employed, it is effectively strapped in place by elastic lash cords. The lab does not require on-site utilities as it carries its own power and water supply. Thus, monitors may be operated for extended periods in remote locations (Dewling, 1969).

In Oregon, trailer-mounted automatic monitors have been in operation since 1968. Two trailers using Schneider Robot Monitors have been operated seasonally at three locations:

1) on the Columbia River at Bradwood, Oregon
2) summer use on the Willamette River
3) and winter use on the Snake River at Milner Dam in Idaho

Both units are capable of measuring pH, conductivity, DO, and temperature. Experience has shown that these monitors obtain very good accuracy (one percent of full scale). Most of the problems are associated with the support equipment. Since trailers are not designed with self-contained utilities, site locations are restricted to areas where power lines or some other power source is available. It has been found that power lines must also be close to the river sampled because of voltage loss due to line resistance. Also, intake pipelines must be kept to a minimum length due to possible change in water quality induced by passage through an extensive length of pipe. As usual, the submersible pump presented the biggest headaches and maintenance expense. The only problem with the actual monitoring assembly was due to DO probe fouling and aging. A partial solution was found by purchasing DO probes with automatic cleaning devices and larger electrolyte reservoirs (Gary O'Neal, personal communication, 1971).

A unique approach to mobile monitoring has been tried on the Mississippi River. The Honeywell monitors employed are installed in specially equipped boats. Conductivity, DO, pH, and temperature are measured continuously in order to determine the extent of pollution in a hundred-mile stretch of the river. EPA in conjunction with the Metropolitan St. Louis Sewer District are conducting the survey (Honeywell Instrumentation News, Oct., 1969).

The Bureau of Reclamation is mainly concerned with water quantity projects. However, in the California Central Valley Project, water quantity for irrigation and other uses is dependent upon water quality. Thus, beginning in 1965 a series of impressive studies using a Honeywell mobile monitor were performed. Since irrigation water must meet salinity requirements, most of these studies were aimed at gathering knowledge on the effect of tides, freshwater inflow, and weather on the salinity of the Sacramento-San Joaquin River delta water. Two large cities are affected by the water quality of this area: San Francisco and Sacramento. Mobility and operation in remote areas for extended periods (up to 30 days) were two important features of the Honeywell unit. The monitor capable of measuring six parameters--conductivity, turbidity, DO, pH, temperature, and sunlight intensity--was transported in a trailer equipped with a small lab (Anon., Public Works, 1967). The trailer contained its own generator and 500-gallon propane storage tank but also was provided with connections for tapping on to a power line (Marks, 1966). Data recording was accomplished via a strip chart recorder. Extracted data is then computer processed to give maximum, minimum, and mean values for each parameter (Anon., Public Works, 1967).

From 1965 to 1967, monitored data aided the Bureau in controlling stream flows to deter the encroachment of salt water from the San Francisco Bay into the Sacramento and San Joaquin Rivers, to flush salt marshes producing a more favorable winter habitat for ducks and geese, and to dilute industrial pollution during low flow periods so that salmon would again spawn in the San Joaquin River. Other uses included collecting data to help in the planning of new water impoundment projects on the American River above Sacramento and supplementing California's grab sampling program by performing intensive surveys of potential and existing pollution problem areas (Anon., Public Works, 1967).

Interstate Applications

The early 60's saw the beginning of the application of automatic instrumentation to monitor water quality on a regional, drainage basin basis. First, developments in this area were undertaken by the Ohio River Valley Sanitation Commission, ORSANCO (Anon., Chemical Engineering, 1963). Much preliminary thought and investigation was given to an automatic water quality data acquisition before a formal program was initiated in 1958. The first phase of this project was to investigate instrument availability, capability and reliability. This was followed by the selection of instrument type and the installation of a prototype system. Electrochemical probe type analyzers were found to be preferable to automatic wet-chemical units because of the signal requirements of the telemetry component and the remote location of the monitors making reagent replenishment difficult. The probe type unit chosen was designed by Schneider Instrument Company and was termed "Robot Monitor." These analyzers were capable of measuring pH, temperature, conductivity, DO, chlorides, ORP, and solar radiation. The prototype unit was an integrated system consisting of the three basic modules mentioned earlier. Operational as of September, 1960, the prototype unit employed telemetry with data being transmitted to ORSANCO headquarters in Cincinnati, Ohio. There, a data logging facility was provided. Successful operation of the prototype unit allowed for expansion of the system. The resulting network consisted of six telemetry units on the upper Ohio and five on-site strip chart recording units stationed on the lower Ohio (Cleary, 1962).

The ORSANCO system now comprises 27 automatic monitoring stations (17 on the Ohio and 10 more on tributaries) (ORSANCO Twenty-First Yearbook, 1969). In addition, a mobile version of the robot analyzer has been used in special studies. This unit employs on-site strip chart recording (Anon., Chemical Engineering, 1963).

The *in situ* system is fully integrated with data telemetered to a central receiving station where an IBM 1130, 2B computer processes it (Klein, *et. al.*, 1968). Data is not just compiled and stored. Statistical analyses are performed resulting in monthly and annual reports. Reports contain tables, graphs, charts, and qualigrams showing maximum, minimum, and average values for each parameter in relation to station, time of year, and water quality criteria. Naturally, these reports are excellent for public relations and aiding state and ORSANCO officials in evaluating the effectiveness of their pollution control efforts (ORSANCO Quality Monitor, Oct., 1970; ORSANCO Twenty-First Yearbook, 1969).

Paralleling ORSANCO's developments, the Interstate Commission for the Delaware River Basin, INCODEL, in cooperation with the Delaware Water Pollution Commission, the USGS and the City of Philadelphia Water Department, initiated an automatic water quality monitoring system for the Delaware River and Estuary (Anon., Water ans Wastes Engineering, 1961). The USGS role in this overall network has already been explained (see section on Federal Applications).

While the USGS was working on the estuary, INCODEL, following a similar path to ORSANCO, contracted with the Lehigh Water Resources Research Council to research the feasibility of establishing a monitoring system on the Delaware River. Preliminary investigations involved researching instrument availability, capability, and reliability. A prototype system was installed in 1959 at Riegelsville, New Jersey. Employing on-site strip charts, temperature, pH, conductivity, DO, and turbidity were continuously recorded. Only a few months' operation was necessary to warrant the construction of eleven additional stations to be constructed between Hancock, New York, and Trenton, New Jersey. Plans were made to have these integrated into a network employing telemetry and a central receiving station (Anon., ASCE 28th Progress Report, 1960; Parker, 1961).

Data from the USGS and the INCODEL systems provide necessary data to the subsequently formed Delaware River Basin Commission in which many agencies cooperate to manage the Delaware River and Estuary. (Agencies involved are: EPA, USGS, Delaware Water Pollution Commission, New Jersey Department of Health, Pennsylvania Department of Health, and the City of Philadelphia.) Along with grab sampling data, continuous records from the automatic systems helped to supply the data necessary for formulating a mathematical model of the River and Estuary. This model has been very useful in guiding water quality management practices on the River and Estuary (Smith & Morris, 1969).

State Applications

Many states on their own have entered the field of automatic water quality surveillance. Most noteworthy is New York's Empire State system. The main purpose of this automatic network is to "provide a rapid intelligence system" to protect the waters and water users of the state. Emphasis is placed on rapid retrieval and analysis of data to yield instantaneous reports on the prevailing water quality conditions (Maylath, November 1970).

Like the interstate systems mentioned previously, much preliminary research was necessary before any installations could be made (research began in 1960). A prototype network was installed in 1966 with the purchase of two electrochemical probe type monitors (Maylath, 1970). An exhaustive study of wet-chemical monitors revealed that they were really not satisfactory for unattended field use (O'Brien & Olsen, 1970).

Field experience using the prototype probe system yielded the following conclusions:

1) Automatic monitors, if applied in a true real-time computer approach, are necessary to supplement a grab sampling program.

2) A well-trained team of engineers and technicians is necessary to maintain the system.

3) The monitoring system should be expanded (Maylath, 1970).

Thus, steps were taken in 1969 to produce a small-scale monitoring network consisting of 12 monitors, with telemetry and central computer processing of data. A Burroughs B3500 computer was the heart of the system (Burroughs Corp. News Feature). Every attempt was made to incorporate the latest design features into the monitoring system. Monitors were equipped with sensors measuring pH, DO, conductivity, water temperature, turbidity, stage, dissolved chlorides, dissolved fluorides, solar radiation and air temperature. In addition, environmental parameter alarm sensors, automatic samplers, equipment status sensors, and functional command equipment were included for better control of analyzer operation. Monitors were housed in trailers equipped with a lab plus air conditioning and heating. Leased telephone lines were employed to transmit data to the central computer station (Maylath, 1970).

Monitoring stations were polled every hour with data traveling to the computer and remote terminals. Remote terminals are an integral part of the overall system since they are installed at water and waste treatment plants. Data received here is instantaneously available for altering plant processes in relation to prevailing water quality and quantity. Data received at the computer center is also displayed for rapid control of the water resource. However, statistical analyses are also performed which are the basis for daily, monthly, and annual reports (Burroughs News Feature, 1970; Maylath, November, 1970).

Future plans are to enlarge the small scale system into a basin by basin network all telemetering data to the central computer processing station. Mathematical models of each basin are being prepared. Data from the basin networks will then be inputed into these models to ascertain:

1) the water quality at all points in a stream (not just at the monitoring station)

2) prediction times for pollutant spills to travel downstream

3) the source of a pollutant

4) the best location, design, and operation of water and waste treatment plants (Maylath, November, 1970).

A less sophisticated monitoring system was initiated in New Jersey in 1968. Of the 10 monitors purchased, four were two parameter resistance type analyzers, while the rest were capable of measuring five water quality characteristics. Five parameter units monitored conductivity, water temperature, pH, turbidity, and DO. They were housed in specially built structures for environmental protection. Utility lines provided power for the system. Data retrieval was via punched paper tape. Tapes were picked up once a week, edited, and processed by computer. Processed data consisting of maximums, minimums and means was used to establish trends in water quality of the streams monitored. Trends were displayed graphically.

The two parameter systems were much simpler. Conductivity and temperature were measured with data being registered on a Fisher Porter automatic digital recorder. Units did not require specially built houses but were installed in location. One advantage of the two parameter system was its ease of installation and relatively maintenance-free operation. The unit also requires no outside power source, as it is battery powered (Anderson, et al, 1970).

Automatic monitors were needed in Pennsylvania on a special survey of acid mine drainage. ProTech Company supplied the automatic system in 1965. The system consisted of two three-parameter units capable of measuring pH, conductivity, and temperature. Units were operated on the Susquehana River at two sites, United Gas Industries and Merc Chemical Company. Data logging was accomplished in two ways via printer (Presin Company) and punched paper tape (Fisher & Porter).

As designed, the system did not meet Federal Water Pollution Control Administration (FWPCA) requirements (see Mentink, Specifications for an Integrated Water Quality Data Acquisition System, 1968, eighth edition). Thus, many operational problems were encountered which eventually led to the return of equipment to ProTech. Nearly all of the poor performance was attributed to lack of design continuity and poor design features of the analyzer which did not provide for adequate sensor cleaning, minimal settling in the flow chamber, modularity, chassis mounting, cabling, panel meter display, internal electronic calibration check or color coded wiring.

Attempts at improving the system still resulted in unacceptable operation. Thus, the Pennsylvania Department of Health asked for assistance from the FWPCA. As a result, the FWPCA performed a complete investigation of the design and operation of the ProTech system and also researched alternate methods of obtaining the desired data. It was concluded that nothing could be done to salvage the ProTech system and that it should be phased out in favor of one of the alternate methods examined. The alternate methods examined were other automatic data acquisition systems meeting FWPCA specifications and various manners of grab sampling. Information from this research was supplied to the Pennsylvania Department of Health which would have to decide on the method to be used, based on the level of the state's commitment to water quality surveillance (Mentink, 1970).

Mobile monitors have been selected by other states for water quality surveillance. Wisconsin's State Division of Resource Development chose a mobile water quality monitor to supplement their grab sampling program (Anon., Public Works, 1968). The Division (now the Department of Natural Resources) felt that such a unit would be very useful in special surveys and in determining the diurnal variations at monthly grab sampling stations (Schraufnagel, Personal Communication, 1971). Such information would eventually help to formulate the desired water quality standards, locate sources of pollution, and find the cause of algae blooms in Wisconsin lakes (Anon., Public Works, 1968).

The Honeywell mobile unit is housed in a 14-foot trailer and measures water temperature, DO, pH, ORP, conductivity, chlorides and solar radiation. The trailer contains laboratory space, a sink, and cabinets so that on-location chemical analyses of grab samples can also be performed. The trailer is environmentally controlled, being supplied with air conditioning and heating. Power is provided by a propane-fueled 5 kw generator. A 500-pound propane storage tank is attached to the trailer (Anon., Public Works, 1968).

During the few years it has been in operation, the mobile unit has supplied reliable data at eight-minute intervals sampling frequency. All data is recorded on an electronile 15 potentiometer (strip chart recorder). Operational experience has shown that cold weather use presents a problem due to freezing of intake and outlet pipes. Also, the chloride probe has not performed satisfactorily.

Eleven new *in situ* monitors have now been purchased from Automated Enviornmental Systems, Inc. (AES). They will be located on two of the most troublesome rivers. The AES monitors will measure DO, temperature, pH, and turbidity, and will telemeter data via telephone lines to a central computer processing center. Here, data will be displayed by teletype and functional commands will be delivered from the computer to the monitors (Schraufnagel, Personal Communication, 1971).

In Washington, the Department of Ecology in 1969-70 employed an AES mobile monitor to collect historical data on Washington waters. The AES unit employed is housed in a trailer equipped with two propane storage tanks and a generator. Thus, the unit may be operated in remote areas away from power sources. Parameters measured are: DO, temperature, conductivity, turbidity, pH, and chlorides. A regular half hp submersible pump supplies water to the flow chamber of the monitor.

In 1970, summer operation for 55 days yielded a 33-day usable record. Some trouble with sensor operation was noticed with only pH, temperature, and DO sensors working consistently. However, most of the downtime (responsible for loss of usable record) was due to support equipment failure. The submersible pump was primarily at fault, but the generator was also a source of problems. It was determined that increased efficiency could be obtained by providing a separate trailer for carrying the propane tanks and generator. Also, daily servicing was found necessary to insure proper operation of the unit (Palko, Personal Communication, 1971).

A relatively unique approach to mobile water quality monitoring was tried by the Texas Water Pollution Control Board. Because of pressure from a sportsman's organization, a comprehensive water quality study of Galveston Bay was initiated in 1963. Due to the large area involved, it was determined that a mobile, automatic monitoring device should be employed. The first unit, called the Stargazer, was an inboard 38- by 11.5-foot boat equipped with a 250 hp motor. An on-board laboratory was provided containing an improvised automatic monitoring system with DO, conductivity, pH, and temperature sensors and separate recorders. Power for the system was provided by a 1.2 kilowatt gasoline generator. A one-fourth hp bilge pump supplied water to the sampling line which was manifolded at the site of the sensors. Later, the system was transferred to the "Little Dipper," a 150 hp inboard-outboard boat.

During a 34-month period, 17,000 field analyses were performed using the above setup. One hundred and eighty sampling stations were established requiring 418 miles of boat travel. Readings were taken at the sampling stations during the regular run and special surveys for 26-hour periods were accomplished in 1964 at points other than the regular sampling stations. Data collected will aid the Texas Water Pollution Control Board in its effort to develop a long-range plan for controlling water pollution in the Galveston Bay area (Davis, 1966).

Municipal Applications

While federal, interstate, and state applications are aimed at obtaining data on the quality of fresh and saline waters, municipal applications are primarily involved with acquiring data on the influent and effluent character of water entering water and wastewater treatment plants. Regardless of this difference in objectives, the same automatic monitoring instrumentation is employed.

Urban monitoring systems have been employed to better manage water and waste treatment plants and to evaluate and improve treatment plant processes. Salvatorelli (1968) gives a good rundown of the application of automatic monitors to process control in a waste water treatment plant. Sensors typically employed are DO, pH, ORP, T, and Cl. Dissolved oxygen and ORP are used to monitor the oxidation process occurring in the aeration tank. Digestor operation is monitored by pH and temperature sensors. The chlorine sensor is utilized to measure the chlorine concentration in the contact chamber and to check residual chlorine levels. Salvatorelli states that such systems are a must for optimal treatment plant operation. He maintains that instrument costs only run 3.5 to 4.5 percent of the total treatment plant construction costs and that after proper personnel training for monitor maintenance yields a completely dependable and reliable monitoring system.

Application to an urban water supply system is well exemplifield by the integrated network established in Chicago. The Greater Chicago Metropolitan Sanitation District was forced into installing an automatic monitoring system for four reasons. One, population was increasing rapidly with a present waste load from 5-1/2 million and an industrial equivalent to 2-1/2 million more. Two, a large collection system was involved (860 square mile area). Three, enactment of state water quality standards made standards compliance necessary. And four, two U.S. Supreme Court rulings had limited the amount of water Illinois could divert from Lake Michigan and further stipulated that no additional requests for diversion water would be accepted until all possible methods of efficiently using existing water had been exhausted.

Installed in July 1968, the system consisted of an integrated network of eleven monitors relays data to a central computing facility and directly to water users at the three main treatment plants. Continuous data is received at the treatment plants and is recorded on strip charts. Hourly values are transmitted to the central computing facility which is staffed 24 hours a day. Here, data is available for instantaneous display by teletype printed on log sheets and also is recorded via punched paper tape for statistical review.

The system was designed by Bristol Company, with instrumentation supplied by Fairchild Space and Defense System. Monitors are housed in either existing buildings or specially built structures. A composite sampler is provided so that laboratory analyses can be performed for water quality characteristics not capable of automatic measurement. Parameters measured automatically are DO, water temperature, conductivity, pH, ORP, chlorides, turbidity, and solar radiation. Submersible pumps supply water to the monitors.

Because of the highly turbid and polluted waters sampled, a well disciplined maintenance program was particularly important for this system. Servicing was on either a weekly or biweekly basis, depending on the station. Calibration was accomplished at intervals of two to four weeks, depending on the sensor and station. Automatic water jet cleaning devices were also intalled at some locations. Jets would operate hourly just before parameter measurement. A maintenance crew of five people was needed to perform monitor servicing. Two of these were electrical engineers, and the other three were instrument mechanics.

Information gathered will aid the Greater Chicago Metropolitan Sanitation District in determining the optimal distribution of water from diversions to maintain minimum water quality standards in receiving waterways (Lanyon & Kurland, 1971).

The benefits gained by continuously monitoring urban water collection systems is explained by Sahre (1970). Reference is made to the Detroit system which was designed to monitor both qualitative and quantitative characteristics of treatment plant receiving waters. He emphasizes the role automatic monitoring plays in detecting improper plant operation and thus in preventing unnecessary spills. He also points out that the information gained will be valuable for improving the design and operation of sewer and drainage systems.

Some quasi-automatic systems employing Technicon Auto Analyzers have been developed to survey and improve treatment plant processes. These systems are composed of two parts: automatic samplers followed by automated wet-chemical analyses with an Auto Analyzer. The Minneapolis-Saint Paul study is an example of one such system. Here, the Technicon system was used to measure MBAS, COD, chlorides, iron, ammonia nitrogen, phosphates, and urea. Information obtained was valuable for evaluating this combined sewer system, yet only data from sewer level and rain guage monitors were treated on a real-time computer processing level employing telemetry (James J. Anderson, et al, 1967).

A similar investigation involving only one treatment plant (Hyperion in Los Angeles Count, California) is described by Garber, et al (1965). Here, Technicon Auto Analyzers were used to evalute the aeration efficiency and the quality of secondary effluent.

Applications in University Research

In a few instances, automatic monitors have served as a tool aiding the university researcher in a solution to a particular problem. Weiss and Oglesby (1963) utilized automatic monitors to help them determine whether vertical oscillations in the metalimnion of an impoundment reservoirs permit material transfer into either the hyper or hypolimnion. The system described consists of a two-parameter unit containing several temperature probes and a galvanic cell oxygen analyzer. Temperature and DO profile data were collected and telemetered to the researcher's lab where recording was accomplished by strip charts and punched paper tape. The researchers believe that information gleaned from surveys such as theirs will be valuable for selecting water of optimum quality from storage reservoirs.

Ingols (1967) used a Honeywell W10 monitor to study the effect of storms on water quality. Parameters recorded were DO, water temperature, conductivity, turbidity, pH, stage, air temperature, and solar radiation. A continuous record was provided using a strip chart. The W10 monitor was housed in a mobile van supplied with a gasoline generator. Stations were selected near utility poles, however, since the generator required maintenance up to three times per day. Data collected were analyzed for comparisons between water quality and flow.

Applications in Canada

The Ontario Water Resources Commission has taken a unique approach to automatic monitoring. In 1969, the Commission initiated a monitoring program using two submersible water quality meters. These immersion monitors were provided by Plessey Canada, Ltd. The units were completely self-contained. They are battery powered with sensors, analyzers and output component packaged together in a cylindrical submersible housing. Parameters measured were time, depth, temperature, turbidity, conductivity, pH, and DO. A current meter was [illegible] in conjunction with the immersion assembly.

Water quality data were correlated with current velocities and directions (Palmer & Izatt, 1970). Data recording was accomplished by magnetic tape cassette at fixed intervals from one to six hours (Palmer, Personal Communication, 1971).

The objective of the monitoring program is to provide water quality data for math models which attempt to predict the dispersion characteristics for nearshore areas of the Great Lakes. Since the water quality of these areas is known to be highly complicated, variable continuous data records are needed. Markov chain and time series analysis are used in analyzing the data (Palmer & Izatt, 1970).

The 1969 survey was performed on Lake Erie at nearshore areas around Nanticoke. Results indicate that conductivity is directly related to water movements in these areas (conductivity can be treated as a passive contaminant). Dissolved oxygen and pH exhibit diurnal relationships and seem uncorrelated with water currents (Palmer & Izatt, 1970).

Math model of the dispersion characteristics will be useful for determining:

1) the best location for water intakes and waste outfalls from the dilution point of view;

2) the acceptable discharge concentrations and flows on the basis of not exceeding desirable values at locations in the priximity of the discharge point on a probability basis (Palmer, 1970)..

The Ability of Automatic Monitoring to Satisfy the Data Needs of State Water Pollution Control Agencies

The previous discussion has shown how automatic monitors are applied in water quality surveillance programs. However, two very basic and important questions remain unanswered: 1) why is automatic water quality data collected, and 2) what is the data used for once it has been collected. Answering these questions will help to define the ability of automatic monitors to satisfy the data needs of state water pollution control agencies.

The foundation for understanding the need for and the utility of automatic monitoring data is based on two facts: 1) grab sampling has many shortcomings when applied to situations where water quality fluctuates rapidly, and 2) water quality management is becoming more complex, requiring real-time data.

To begin, Klein, et al (1968) states that there are three deficiencies in grab sampling programs:

1) cost
2) limitations on the frequency with which analyses can be made
3) time lag between collection of samples and receipt of analytical results for stream evaluation purposes

Cost and limitations on frequency must be considered together. Frequency limitations are mainly related to manpower limitations. As applied to grab sampling, increased sampling rate means increased field and laboratory personnel to collect and analyze samples. A concurrent increase in operational expenses of course follows (Anon., Electronics, 1970 - quoting William T. Sayers).

In comparison, the major advantage of automatic monitoring is the increased capability for high frequency sampling (Ballinger, 1971). Nevertheless, automatic instrumentation does not eliminate field and laboratory personnel because of the necessity of periodic maintenance on automatic equipment (Sayers, 1971). Indeed, personnel requirements are such that higher salaries are required to obtain people with the right qualifications (Sayers, 1971).

While automatic monitoring has some advantages with respect to manpower limitations, the wealth of data produced increases operational costs due to the necessity of expensive data handling procedures (Sayers, 1971). Effective data interpretation and analysis requires digital computers (Ballinger, 1971). ORSANCO's robot monitor system collects so much data that it would take 150 man-years to process all the data collected during only one year (Klein, et al, 1968).

Taking the above factors into consideration, as well as installation and maintenance equipment cost associated with automatic monitoring, automatic instrumentation is favored on a least cost basis when a sampling frequency greater than daily is desired (Ballinger, 1971).

However, the trade-off between automatic and manual sampling involves other considerations also. According to Klein, et al (1968), the third deficiency of grab sampling was the time lag between collection and receipt of analytical results. This topic will also be discussed later in relation to the need for real time data for water quality management. For the purposes here, it will be sufficient to note that grab sampling programs entail time consuming collection analysis procedures (Cleary, 1962). Grab sampling programs applied to situations involving rapid fluctuations in water quality may be very inefficient and expensive due to the large proportion of time spent in collection of samples and travel between stations and to the laboratory (Mentink, 1970).

Another problem in grab sampling associated with time consuming collection and transportation is the retrieval of a representative sample. "In general, the sooner the samples are analyzed after the collection, the more reliable the data" (Ball, 1970). This is true because after sample collection, changes in composition may occur rapidly (Glenn, 1970). Parameters such as temperature, dissolved gases, and pH are subject to rapid alteration upon collection and "must be measured in the field" (Ball, 1970). Other parameters such as BOD, NO_3, and PO_4 can change significantly with time and precautions (e.g., refrigeration) should be taken to assure minimum sample degradation between field collection and laboratory analysis (Ball, 1970).

Another important consideration in comparing manual and automatic monitoring is the relative compatibility of a particular water to either method of evaluation. To explain, some waters exhibit rapid fluctuations in water qualities while others show relatively slow changes (Thomann, 1970). "In any sampling, the frequency of sampling is directly related to the rate of change of a given paramter " (Ballinger, 1971). Thus, some water are naturally more conducive to automatic monitoring than others (Thomann, 1970; Ballinger, 1971; Ballinger, 1968). The proper sampling frequency for any water can be determined by spectral analyses. Ironically, this requires a "relatively large amount of data" (Ballinger, 1971).

The above discussion has described some of the deficiencies of grab sampling. Most of these limitations are related to monitoring programs requiring detection of rapid fluctuations in water quality. As pointed out, herein lies the major value of automatic monitoring, the capability for high frequency sampling. The question now is: Why is it necessary to detect rapid fluctuations in water quality? Smoot(1970) supplies a concise answer to this question:

> Today many complex water-quality problems associated with protecting and improving our environment frequently require immediate evaluation and prompt action.

This applies to the field of water supply and pollution control where "more and more, real time data networks are being recognized as essential in providing the current information necessary for good water-quality management" (Smoot, 1970). For some time, water resource managers have desired to keep continuous tabs on upstream conditions so that good water quality could be maintained for downstream users (Jones, 1961). The need for continuous tabs on water quality is a direct result of the increased quantity and variety of waste matter entering our nation's waters (Jones & Joyce, 1961; Cross, 1968). True, some waters do not fit this description and are still blessed with good quality due to sparse population and large stream flows in relation to pollution loads. In these areas, only modest sampling programs may be sufficient (McDermott, Ballinger and Sayers, 1968). However, Elving (1967) states that any flowing water constitutes a constantly changing and dynamic system which must be monitored continuously. Moreover, in some areas of dense population, complex waste sources, intensive water use, and rapidly fluctuating water quantity, day-to-day water quality management requiring continuous automatic monitoring is needed (McDermott, Ballinger and Sayers, 1968).

Ability to Satisfy Planning Data Needs

Long-range planning connotes the use of math models. Data needed for math models "must be perfect continuous records with no sags or bad readings" (Palmer, 1970). This basic requirement is satisfied by automatic monitoring which supplies large quantities of continuous inexpensive data (Palmer, 1970). Ballinger (1971) agrees in that automatic monitors provide large amounts of data in short time intervals which are valuable as input into predictive river basin models. Also, automatic data is very suitable to certain statistical analyses often used in water quality models: time series analysis and Markov chain (Palmer, 1970; McCartney & Beamer, 1962).

River basin models based on automatic data have much planning utility. They are useful as an aid in locating municipal and industrial intakes and outfalls (Palmer, 1970; Glenn, 1970). In New York, the Empire system provides pertinent data to "improve the precision of math models predictions" (Maylath, 1970). These predictions are the basis for formulating design and operational criteria guiding the construction and operation of water and waste treatment plants. New York also plans using monitor data in the preparation of stream models useful for water quality forecasting (Maylath, 1970). Using deterministic and probabilistic BOD-DO models based on continuous DO measurements and BOD waste load determinations, downstream DO predictions can be made knowing upstream conditions and events (Boes, 1970). Automatic data plugged into predictive models can also yield information on water quality conditions at non-sampled sites and at any time of day (Glenn, 1970; Maylath, 1970).

Ability to Satisfy the Data Needs for Regulation

A state water pollution control agency concerned with regulating water quality is interested in detecting pollution, determining its source, and seeing that the pollution is abated. There is little question about the ability of automatic monitors to detect pollution. One of the main assets of automatic monitoring lies in its ability to detect abnormal water qualities (Klein, et al, 1968). In this respect, automatic monitoring surpasses manual monitoring as "grab sampling, even at frequent internals, may not detect undesirable levels in time to permit effective counter measures" (Ballinger, 1971). Automatic instrumentation, however, has the capability of sounding an alarm and/or collecting a sample for further analysis once an abnormal variation in water quality has been detected (Keyser, 1965; Parker, 1961). Also, as mentioned earlier, one of the deficiencies of grab sampling lies in the difficulty of maintaining a representative sample. Sample degradation can occur due to the time lag between collection and analysis (Ball, 1970).

The ability of monitors to detect abnormal changes in water quality and collect a sample at these times has significance for determining pollution sources. Analysis of the collected sample may indicate the particular waste causing the abnormal water quality. Knowing the nature of the pollutant may be valuable for locating its source (Ballinger, 1971). A good example is the tracing of two fishkills to a common cause by the ORSANCO Robot Monitoring System (Klein, et al, 1968). The advantage of the large spacial distribution of the ORSANCO network was brought out in tracing the source of widespread low DO readings to natural cuases (Klein, et al, 1968). A similar situation existed on the USGS Delaware system in April, 1963, when DO values were depressed below 3 ppm. Again, the monitoring network traced the source to natural causes (Anon., Chemistry and Engineering News, 1963).

Electronic monitors are also very amenable for detecting diurnal fluctuations in water quality characteristics; especially for documenting DO sags (Ballinger, 1968; Kleinert, Personal Communication, 1971).

Making data readily available to water quality agencies is an important part of pollution abatement. "Those who are active in water resources management agree that any pollution abatement program must be preceded with the acquisition of a continuing intelligence on the quality of all our rivers and streams (Shubrooks, 1968). Merely collecting data is not enough; it must also be made readily accessible to those concerned with controlling water quality (Shubrooks, 1968).

Once the data is made available, it must also be used. A rapid intelligence system of automatic monitors, telemetry, remote terminals and central data logging and analysis facilities provides a highly effective means of water quality regulation (Maylath, 1970). As mentioned earlier, instantaneous relay of water quality conditions allows for alternation of treatment plant processes to conform to the quality of receiving waters (Maylath, 1970; Langon & Kurland, 1971). Monitored data is also useful for determining low flows and the amount of water necessary to supplement stream flows so that standards are not violated. Using automatic data discharges of pollutants can be traced and their effect on the entire water system evaluated (Ballinger, 1971).

Monitored data coupled with math models can be useful for establishing effluent concentrations for industries and waste treatment plants. In this way, the assimilative capacity of receiving waters is not exceeded and compliance with water quality standards is assured (Palmer, 1970).

Data processing of telemetered data allows for rapid report generation. Such reports on an hourly, daily, weekly, monthly, or annual basis are extremely valuable as an aid in regulation, since graphs, charts, and tables can be devised to show the percent of time water quality parameters are in violation of standards. In addition, computer analysis can determine the extent of daily pollution loading, including: dissolved oxygen deficits, suspended solids loads, salt water intrusion, acid loads from mines, caloric loading from thermal pollution and waste treatment plant effluents (Ballinger, 1971; Elving, 1967).

Needed Improvements in Automatic Instrumentation

The previous section has cited the advantages of using automatic instrumentation for water surveillance. Nevertheless, even with sophisticated telemetry systems, present-day water quality surveillance leaves much to be desired. The fact is that most state and federal agencies are still not able to determine whether our nation's waters are getting better or worse (Cleary, 1970).

Disadvantages of Present Instrumentation

Agencies are handicapped because monitoring systems still fail to supply the right data (Cleary, 1970). Automatic monitoring has many shortcomings in this respect. In 1960, at a "Conference on Water Quality Management and Instrumentation" held in Cincinnati, Ohio, it was pointed out that data processing technology was sufficient for water quality monitoring but that much research on sensing devices was needed. Ten years later at a similar conference (National Symposium on Data and Instrumentation for Water Quality Management) held in Madison, Wisconsin, the same conclusions were reached (Lyons, 1970). It is now generally recognized that data recording and processing represents the strongest link in the automatic water quality data acquisition system because it is fully developed and relatively trouble free (Smith, 1970). Similar words cannot be spoken for sensing devices. Most experts agree that in the last ten years, little progress has been made in developing new automatic sensors (Lyons, 1970).

The reason for this lag in the development of new sensors is twofold. One, as mentioned earlier, initial emphasis on developing automatic water monitoring instrumentation was focused on supplying monitors for industrial process control (see section on application of automatic monitors). Two, instruments devised for this purpose were merely adaptations of existing laboratory instruments (Considine, 1965). Thus, development of automatic field equipment paralleled and was dependent on the development of laboratory and process control instrumentation. This process has resulted in the deplorable situation where field sensors "represent parameters for which electrode systems are readily available--and do not include many measurements vital to the adequate characterization of water quality" (Ballinger, 1968). (See Figures B -1 and B -2.)

The past ten years have not been completely fruitless. Development of specific ion electrodes and wet chemistry monitors has had some impact on alleviating the above problem. Specific ion electrodes can broaden the spectrum of sensor detection to include some specific water quality parameters. In general, ion selective electrodes detect ions in solution, thereby developing an electrical potential in proportion to the activity of the ion (Riseman, 1970); Kaminski, 1969). The chloride ion is an example of such an electrode presently used in automatic water quality monitoring. However, other specific ion electrodes available for laboratory use are "not satisfactory for monitoring purposes" (Ballinger, Personal Communication, 1971). This includes electrodes for measuring important nutrient parameters (e.g., nitrates and phosphorus). Electrodes for these parameters do not process adequate sensitivity and fail to truly measure the desired constituents (Ballinger, Personal Communication, 1971).

Another serious problem is interference from like ions. Pretreatment of a water sample can be performed in the laboratory to minimize these effects, but this is difficult under field conditions (Riseman, 1970).

Acidity
Alkalinity
Ammonia
Arsenic
Barium
BOD
Boron
Bottom Deposits
Cadmium
CCE
Coliform

Chloride
Chromium
Color
Copper
Cyanide
Dissolved Oxygen
Electrical Conductance
Floating Solids
Fluoride
Hardness
Hydrogen Sulfide

Iron
Lead
Manganese
MBAS
Nitrate
Pesticides
pH
Phenols
Phosphates
Plankton
Radioactivity
Selenium

Settleable Solids
Silver
Sodium
Sulfate
Suspended Solids
Taste & Odor
Temperature
Total Dissolved Solids
Toxic Substances
Turbidity
Zinc

Figure B-1. Water Quality Criteria in State Standards. (From Ballinger, 1971....Underlined criteria represent parameters for which sensors are already available.)

	Ranges of Concentration Desired mg/l			Precision Desirable mg/l		
	L	M	H	L	M	H
Organic nitrogen	0-1	-	0-10	0.01	-	0.5
Ammonia nitrogen	0-1	-	0-10	0.01	-	0.5
Nitrate nitrogen	0-1	-	0-10	0.01	-	0.5
Nitrite nitrogen	0-0.1	-	0-2	0.01	-	0.1
Inorganic phosphorus	0-2	-	0-20	0.01	-	0.5
Organic phosphorus	0-2	-	0-20	0.01	-	0.5
COD	0-50	-	0-500	1	-	10
MBAS*	0-1	-	1-10	0.01	-	0.1
Acidity or alkalinity	0-250	-	0-1000	5	-	50
Hardness	0-250	-	0-1000	5	-	50
Sulfate	0-100	-	0-1000	2	-	20
Phenols	0-0.5	0-5	0-50	0.01	-	0.1
Calcium	0-100	-	0-1000	2	-	20
Cyanide	0-0.1	0-1.0	0-10	0.005	0.05	0.5
Manganese	0-0.5	-	0-5	0.01	-	0.1
Zinc	0-2	-	0-10	0.01	-	0.5
Sodium	0-100	0-500	0-5000	2	10	100
Potassium	0-10	0-100	0-1000	0.5	5	50
Copper	0-0.5	-	0-5.0	0.01	-	0.1

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*Methylene blue active substances

Figure B-2. Parameters for which Sensors are not Available but are Needed. (From Green, 1966)

Wet chemistry monitors can also broaden the scope of sensor detection. However, severe handicaps must be overcome before this system is suitable for field application (Ballinger, Personal Communication, 1971). Some of these disadvantages are interference from color and turbidity, biological fouling of sampling lines, failure of solenoid valves, reagent supply and disposal, buildup of color complexes on the measurement cell, and slow response of the system--typical time is two hours from sampling to recording (O'Brien & Olson, 1970; Feltz & Smoot, 1969; Ballinger, 1968). Sample filtration has generally been employed to minimize some of these problems. However, this "renders the sample not entirely representative of the source" (O'Brien & Olson, 1970).

Besides not supplying entirely the right data, automatic monitors are still plagued with maintenance problems. Characteristically "automatic monitoring equipment is delicate and unstable" (Blakey, 1970). This is evident from operational experiences in which typical monitoring systems require weekly maintenance. Sensors require cleaning and calibration due to biological and sediment fouling causing electronic drift (Blakey, 1970). Self-cleaning with automatic wipers, water jets or ultrasonics may eliminate this problem (Ficken, 1970).

Pump failure remains the number one maintenance problem. Semi-positive displacement submersible pumps are advantageous since they do not aerate or deaerate the water sample. However, they are disadvantageous because of frequent breakdown due to electric motors burning up and metal fatigue producing pump strator breakage (Maylath, 1970). The problem arises from placing pumps in the harsh stream environment where they are naturally subject to strain, abrasion, and clogging from sediment, organic debris and biological growths on the pump itself (Feltz & Smoot, 1969).

Another limitation of significance is aging and depreciation of equipment. Solid state circuitry, amplification of sensor signals, maintenance of proper velocity of sample through the flow cells, and large electrolyte reservoirs are helping to extend the life of and provide long-term stability for automatic sensors (Bromberg & Carames, 1970; Klein, et al, 1968). Nevertheless, sensors and other monitor components do wear out and require replacement (Bromberg & Carames, 1970). (See Figure B-3.)

Rising costs of automatic monitors are another drawback. The trend of instrument manufacturers is to produce more complicated, costly systems, which is in direct opposition to the needs of the users who desire simpler, more reliable and less expensive instrumentation (Klein, et al, 1968).

Other considerations and limitations include freezing of pump and sampling lines during winter operation, salt bridging and corrosion of mechanical parts during operation on saline

Parameter	Replacement Interval	Tolerance
Dissolved Oxygen	12 weeks	± 0.25 mg/l
pH	4-5 months	± 0.1 units
Temperature	6-12 months	± 1 °F
Oxidation-reduction Potential	6-12 months	12 mv

Figure B-3. Replacement Interval and Tolerance for Some Automatic Sensors. (From Bromberg & Carames, 1970) waters, vandalism, and high initial costs of land acquisition and installation (Maylath, 1970; Bromberg & Carames, 1970; Ballinger, 1971).

Future Needs

The above discussion has already pointed out many of the improvements needed by explaining the disadvantages of present systems. Some specific suggestions for improvement are:

1) Lessen frequency of cleaning by changing the configuration of the flow chamber so that it has the same internal shape as the water supply lines (possibly have the sensor surround the sample instead of the converse).

2) Develop a standard calibration procedure for sensors (Maylath, 1970).

Other modifications are needed to make automatic monitors more reliable and versatile. The trend in sensor technology is toward developing microcircuit, digital sensors. These sensors would eliminate analog to digital conversion before signal transmission. This not only simplifies data transmission and logging but also provides sensors of greater reliability through the use of microcircuits (Tajima, 1969).

Monitor versatility can be increased by developing satellite and mobile monitors for supplementing major stations and for use in intensive surveys (Maylath, 1970; Ballinger, 1971). Some progress has already been made in supplying monitors suitable for both of these uses. One such system is the immersion or submersible water quality recording monitor (Maylath, Nov. 1970). Portability is an important feature of this unit. The monitor is small, compact and battery operated. In addition, advantage is gained by using submersible sensing and recording instrumentation. The necessity of pumps, intake and outlet lines, and a shelter to house the monitor is eliminated. Also, a representative sample is assured because measurements are taken and recorded in stream. On shore data logging and telemetry is also possible via external terminals attached to the submerged monitor (Palmer, 1969).

One disadvantage is the difficulty in maintenance due to in-stream placement of the monitor. Such a location is awkward for servicing since removal from the stream is required. Under times of cold weather or high water, this can become quite a chore. Also, in-stream placement allows for increased possibility of damage due to floating debris, change in water flow, biological and sediment fouling, and vandalism (Ballinger, 1971; Ballinger, 1968).

Mobile adaptations of *in situ* monitors can also be employed as satellite monitors and in intensive surveys. Most *in situ* systems can be modified for mobile operation without significant change in design (Ballinger, Personal Communication, 1971; Ballinger, 1968). Mobile operation has some distinct advantages. Most obvious is the fact that such units "provide maximum flexibility in sampling location" (Ballinger, 1971). It is this asset which makes mobile monitors valuable in intensive surveys because of their capability to sample for short periods at a number of critical points. Other advantages are: 1) ease in maintenance, and 2) reduction in the initial expenditures for land acquisition and installation (Ballinger, 1971).

One disadvantage of mobile adaptations of *in situ* systems is the problem of inadequate operation of support facilities (i.e., propane storage tank and generator) (Ballinger, 1968).

The benefits derived from mobile operation could be increased if mobile monitoring were expanded to include buoy-type or float systems (Anon., Electronics 1970--quoting William T. Sayers). Two applications have been cited under the section on Historical Review of the Use of Automatic Instrumentation for Water Pollution Control (St. Louis and Texas Water Pollution Control Board projects). In addition, research on a floating system housed in a small boat has been conducted by Raible and Testerman (1969) at the University of Arkansas Graduate Institute of Technology.

The last point to be made, but an important one, is that automatic monitoring data must be used to be effective (Ballinger, 1971; Cleary, 1970). Automatic monitoring produces a wealth of data which requires computer storage and analysis (Klein, *et al*, 1968). Moreover, report generation is extremely important and all water users should be informed of water quality conditions on a real time, daily, weekly, monthly, annual, and long-term basis (Maylath, 1970).

Cost Analysis

A cost analysis of automatic water quality data acquisition systems will vary according to the type of system (*in situ*, mobile, immersion), the recording technique (strip chart, punched paper tape, magnetic tape), and whether or not telemetry is performed. The cost of telemetry systems varies according to the type of transmission, communications link and whether merely data logging or a computer facility is employed. To obtain a feeling for the kinds of expenditures involved, an analysis of three principal cost categories will be examined first:

1) purchase price of instrumentation
2) installation
3) operation and maintenance

Purchase Price of Instrumentation

The initial cost of developing an automatic monitoring system is purchasing the equipment. Monitors conforming to EPA specifications (Mentink, 1968) "cost from $6,000 to $12,000 depending upon the sensors required and the data acquisition employed" (Ballinger, 1971). The five parameter system employed by the USGS on the Patuxent River costs approximately $8,000 (Nauman & Cory, 1971). James J. Anderson (June, 1970), for his case study on the design of urban water data acquisition systems, figured a cost of $8,000 for a six-parameter "Robot Monitor." Mentink (1970) estimates a cost of $7,000 for a four-parameter monitor.

The cost of the monitor usually includes the price of a strip chart recorder, which runs approximately $2,200. If another recording technique is desired, a slightly higher expenditure is necessary. For eight channel punched paper tape, a cost of $6,000 can be expected (Mentink, 1970). Although less expensive in itself ($4,000), sixteen channel tape does not record data in computer compatible format. If data processing is desired, an additional $7,500 for a translator is required, along with $1,600 for a digital clock plus analog to digital converter. Also, a spare reading head for the translator is advisable from a maintenance standpoint. The price of this part is $2,000 (Mentink, 1964; Mentink, 1970). Recording on magnetic tape is also possible. Incremental magnetic tapes run around $5,000 (Mentink, 1970).

In addition to the price of the monitor and recording, the expense of accessories and support equipment must be considered. The sum cost of submersible pumps, intake and outlet lines, sample takers and sensor cleaning devices can be significant. Sensor cleaning by high velocity water jet costs $970, while ultrasonic cleaning runs $2,200 (Mentink, 1970).

If telemetry is not desired, above expenditures constitute the initial capital investment on equipment. With telemetry a higher initial capitalization is necessary. Initial telemetry expenses can be divided into three areas: 1) transmission; 2) interface; and 3) data logging and processing.

Telemetry may be by either analog or digital transmission. For analog transmission, there are two modes: 1) pulse duration, and 2) millivolt to frequency (Smoot, 1970). Both modes require a transmitter at the monitor. For either mode, analog transmitters cost $2,250 (Mentink, 1964). However, a lower figure of $600/location is given by James J. Anderson (June, 1970).

Digital transmission requires higher cost transmitter packages. Mentink (1964) gives a figure of $4,500. Again, Anderson (June, 1970) gives a lower cost of $4,000.

Telemetry also entails expense at the receiving end of the communications system. This phase of the system is referred to as the interface since it receives the transmitted signal from the monitoring stations and converts them into a form suitable for display, recording, data logging, and/or computer processing (Anderson, June 1970).

If pulse duration analog transmission is employed, a cost of $11,500 is possible at the interface phase (receiver and analog to digital converter plus packaging plus engineering). For millivolt to frequency analog transmission, the expense is reduced to $7,500 (receiver + analog to digital converter) (Mentink, 1964). Anderson (June, 1970) figures a cost of $10,000 for this phase, using analog transmission.

Since digital transmission does not require analog to digital conversion at the interface, the cost here is nominal (Anderson, June, 1970).

The interface is located at the central receiving station which can be either a data logging unit or a computer processing and control facility. Data logging units may display and record data on typewritten log sheets and record data for future analysis on punched paper tape or magnetic tape (Smoot, 1970). If analog transmission is employed, the cost of the data logging unit is $20,000. With digital transmission, data logging units cost $22,000 (Mentink, 1964).

Computer processing facilities are employed when more than data logging is desired. Anderson (June, 1970) gives a rundown on the cost of a computer facility with data processing, monitor control, and math modeling capabilities. The The cost of a minicomputer with 4K core memory is given as $15,000. Additional core is available at a cost of $6,000 per 4K words. The disk file costs $40,000 and is necessary if foreground/background programming is desired. Other peripheral equipment needed includes:

1) paper tape punch-reader, $6,500
2) magnetic tape, $28,000 first unit
3) magnetic tape, $18,000 added units
4) line printer, $30,000
5) cathode ray tube display, $4,000 each
6) logging typers, $5,200

In addition, special software systems are important and cost 10 percent of hardware costs, plus $100/remote point. Applications software cost is $5,000/program.

Installation

After purchasing monitoring equipment, the next expense is installation. The literature with respect to this topic is very sparse. The only figures available appear in a recent article by Ballinger (1971). He indicates that an expenditure of from $1,000 to $3,000 in construction costs is necessary for installation.

Operation and Maintenance

Automatic monitors are intended for unattended operation in the harsh stream environment. Yet, the present state-of-the-art indicates that they are unstable and dilicate instruments subject to degradation due to biological fouling, etc., and depreciation because of aging (see discussion on Needed Improvements in Automatic Instrumentation). Given these limitations, it is no wonder that a large portion of the expense of running an automatic monitoring system is due to maintenance expenditure.

Considering only maintenance on the monitors, a figure of $1,250/station/year was determined for the ORSANCO system of fourteen monitors. This is a total of $17,500 for all the stations combined. When maintenance costs at the central receiving station are added, the figure is only increased to $18,600. Thus, only a small portion of the total maintenance cost was attributed to the central receiving station. A breakdown of the maintenance costs on the monitors shows approximately 35 percent for travel, 30 percent labor, 20 percent servicing, and 15 percent parts and supplies (Donnelly, Personal Communication, 1971). Maintenance costs are based on a two-week service schedule (Klein, et al, 1968).

It is interesting to note that the maintenance cost per station per year ($1,250) has not changed despite inflation and holds for ORSANCO's present system of 27 stations.

An analysis of costs for a single monitor system on the Patuxent River shows an annual maintenance expense of $2,700. This figure is comparable to ORSANCO's results, since servicing on the Patuxent River monitor was on a weekly basis. The $2,700 figure includes servicing, recalibration, transportation, and salaries (Nauman & Cory, 1970). Wages paid ranged from $7.50 to $8.00 per hour (Nauman, Personal Communication, 1971).

Besides the maintenance expenses, operational costs include expenditures for telemetry and data processing. Operational telemetry costs are mainly attributable to the communications link. Charges vary according to the type of leased line employed. For telegraph grade (schedule 1001) lines a charge of $ .75 to $1.00/month/mile can be expected (Shubrooks, 1968).

ORSANCO's system utilizers telegraph grade lines and has experienced a yearly cost of $11,300 (611 miles at $1.00/month/mile plus a monthly terminal service charge per location) (Klein, et al, 1968).

EPA experience with the New York Harbor monitoring network showed a cost of $1,980/year for leased telegraph lines for a five-station network and $3,170 for an eight station system (Bromberg & Carames, 1970).

For voice grade lines, the charge is $3.00 to $4.00/month/mile (Shubrooks, 1968). A comparable figure of $3 for the first one-fourth mile plus $1 for each additional one-fourth mile is given by Anderson (James J., June, 1970). In addition, he indicates that an installation charge of $10 per terminal is necessary.

If tone multiplexing is desired with voice grade lines, an additional charge can be expected. For the central receiving station, a charge of $10,000 per eight remote sites per party line is made. For remote sites, a $1,500 charge per site per eight points is assessed (Anderson, James J., June, 1970).

When data processing equipment is leased, it should be considered as an operational expense. ORSANCO leases its data processing equipment at a charge of $23,600 per year. The computer facility contains "an IBM 1130, 2B computing system, with 8K and disk pack, 1134 paper tape reader and 1055 punch, 1442 card-read punch unit, 1132 medium speed printer, and 029 interpreting key punch (Klein, et al, 1968).

Other operational expenses include electric service and salaries. Electric service for the New York Harbor system of five stations was $2,400. Charges figured for an eight-station network were $3,840/year. Salaries for the five-station system were $25,250/year, very comparable to an eight-station network--$25,280/year (Bromberg & Carames, 1970).

An appreciation of the constituent operation and maintenance expenses mentioned above is important. However, a discussion of the total operation and maintenance expenditures is probably more valuable. For the New York Harbor monitoring system of five stations (6 to 8 parameters per station), the total operation and maintenance cost was $31,684 per year (includes salaries, servicing, replacement equipment, leased lines, electric service, and transportation). This is $6,340/station/year. Figures for an eight-station system were $35,189/year, or $4,400/station/year (Bromberg & Carames, 1970).

Anderson (James J., 1970) estimates a total operation and maintenance for an eight-station system (7 parameters per station) at $33,000/year, or $4,125 per station/year.

A total annual operation and maintenance cost for the somewhat larger ORSANCO system (14 monitors--7 parameters per station) is lower, at $53,500 or $3,821/station. This figure includes servicing, telegraph line charges, and leased data processing equipment (Klein, et al, 1968).

Life Expectancy of Instrumentation

Another important consideration which has significant impact on the cost of an automatic monitoring system is the depreciation of equipment. Due to aging (increase in maintenance necessary) and obsolescence, replacement of equipment may be necessary every seven years (Klein, et al, 1968).

Total Annual Cost

Given the seven-year life expectancy, operation and maintenance costs, initial capital investment for equipment, installation, and amortization, the total annual cost of an automatic monitoring system can be determined. For the ORSANCO system (14 monitors), a figure of $74,000 or $5,300/station was computed (Klein, et al, 1968).

Anderson (James J., 1970) estimates a cost of $60,000 or $7,500/station for an eight station telemetry network over a one hundred mile stretch of river. Included in the figure is an amortization rate of 10 percent for a ten-year period.

Without telemetry the cost is only slightly lower for a one station system. Total annual costs for the Patuxent River system averaged $5,000 (Nauman & Cory, 1970).

Mobile Monitors

Actually, the cost analysis for a mobile system will be very similar to that for the *in situ* systems mentioned above. The same monitors can be employed since no significant design change is needed (Ballinger, Personal Communication, 1971). The only real difference is the increased cost for installation since mobile packaging is necessary. Wisconsin's mobile unit intitally cost $20,000, including monitor and trailer packaging. Assuming that the price of the monitor alone was $8,000, the cost of the trailer and installation must have been around $12,000. Total operation and maintenance expenses for this trailer monitor have been $5,000 per year (includes assumed cost of $2,000/year for depreciation of the mobile laboratory) (Kleinert, Personal Communication, 1971).

Immersion Monitor

Since immersion monitors are a fairly recent addition to monitoring technology, little data is available on the costs of such units. However, Palmer (Personal Communication, 1971) has provided the following figures:

Purchase price		$10,000/unit
Remooring electronic check out and calibration	approx.	$ 2,000
Grab sample check on calibration	approx.	$20-travel 30-labor 12-analysis (each time)
Postmooring electronic check out and calibration		$80
Data processing		$65-computer time 10-labor
Further data analysis	approx.	$400-computer time 400-labor (interpretation and report writing
Support system	<	$700

Palmer also commented that immersion units due to their portability and compactness allow easy handling in the field and electronic servicing in the laboratory. This may have a beneficial and significant impact on the maintenance costs associated with these monitors.

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APPENDIX C

REMOTE SENSING: STATE-OF-THE-ART

It is important from the outset to clearly establish the character of remote sensing as applied to solving water quality problems. Remote sensing basically is the acquisition of information about an object without intimate contact between the object and the data-acquisition device. The data are contained in emitted, reflected, or scattered electromagnetic energy that is registered in various ways for subsequent extraction and conversion to intelligent information. A variety of airborne sensing devices (operating during both day and night) and data-analysis techniques are successfully used to gather this information (Chandler, et al, 1970).

This points up the primary difference between remote sensing and grab sampling or automatic monitoring. The number of individual data bits gathered by remote techniques is infinitely greater than the number gathered by either of the other two techniques. Each of the millions of data bits gathered remotely, whether photographically or electronically, is not necessarily quantitative individually, but may be when collectively considered. In contrast, each data bit taken by either grab sampling or automatic monitoring is individually quantitative. The point then is that in terms of quantitative bits of data, it is difficult to compare remote sensing with other sampling techniques. However, as will be shown later, rough comparisons can be developed.

To gain the full benefit of remote systems with technology and interpretative abilities currently available, objectives for gathering data must be clearly and carefully designed. Flights sent out with any combination of sensors to "see what they can do" generally result in an expensive gathering of meaningless and subsequently useless data. Coordination of flights, types of sensors, time of day and many other factors must be carefully calculated and incorporated into a scheme to effectively monitor water quality (Schneider and Kolipinski, 1969).

The most probable areas of application of remote sensing techniques to water quality are divided into six areas by Burnett and White. These six major water pollution problems are as follows:

1. Eutrophication;
2. Metalic ions and toxic metals;
3. Chemicals and oil;

4. Thermal pollution;
5. Suspended solids from domestic sources and mining agriculture; and
6. Saltwater intrusion into fresh groundwater sources.

Correspondingly, there are various remote devices which seem suited to solving these certain categories of water quality problems. Hom (1968) has suggested the following eight regions of application.

1. Photography. Various black and white and color films, in combination with selective filtering devices, provide visual spectral analysis of given pollution scenes.

2. Thermal infrared. Thermal scanning devices in about the 8-14 micron (μ) range indicate within a ± 0.5 C range the apparent temperature of the scene.

3. Microwaves. Comparatively long wave lengths give groundwater temperatures and to some degree ground water levels.

4. Airborne magnetics. Nuclear procession-type magnetometers reveal ground water conditions to some degree.

5. Electromagnetics. Input systems using broadcast radio signals have broad, undetermined application to water quality problems.

6. Gamma-ray spectrometer. This instrument is being developed for effective use as a good indicator of water quality.

7. Chemical vapors. Chemical vapors emitted from the earth's surface may be measured down to seven parts per billion. This fact holds potential for airborne sampling systems.

8. Fluorescent processes. As is the case with chemical vapors, causing hydrocarbons to fluorescing materials may also be recorded to seven parts per billion.

Scope of Remote Sensing

A vast amount of aquatic information may be recorded with the many sensors and interpretation techniques. Perhaps in no other way can large areas containing water resources be examined and the aquatic and ecologic interactions which occur within them be studied (Hom, 1968).

The extraction of the information from the remote systems, however, requires highly qualified personnel for the effectuation of the systems. Literally every phase of the remote sensing operation requires experience and expertise. The planning of the studies must be carefully and imaginatively tailored to accomplish specific monitoring goals. The actual in-flight operation must be precisely conducted to record information as designed in the pre-flight plan. Finally, the interpretation and use of the recorded data must be carried out by skillful and innovative personnel to gain the full potential use from the data.

Because of the highly sophisticated nature of equipment and personnel for the specific application of remote sensing systems to water quality control, it is impractical for most states to consider actual purchase and hiring requirements. For example, the aerial-photographic service at Colorado State University, which may be considered a very complete photographic facility, has in the order of $300,000 invested in aircraft, cameras and interpretation equipment alone (Skinner, 1970). This figure makes no account for the personnel required to operate the equipment. Radar systems and thermal scanning systems may require many times the cost for photographic equipment due to increased size of aircraft and instrumentation necessary for efficient operation.

The expense of purchasing these systems is not, however, a limiting factor for use in state programs. There exist a number of governmental, educational, and private consulting entities through whom all the necessary functions to carry out remote sensing investigations may be contracted. At present, our ability to monitor pollution transport and diffusion mechanisms is confined to known sources and specific types of pollutants, for the most part (Burnett and White, 1970). Therefore, the effective incorporation of remote sensing techniques into state programs must be accompanied by precise ground-truth correlations.

A state which desires to evaluate and improve its present water quality monitoring system may use remote sensing to great advantage. As previously mentioned, remote sensing can, first of all, provide an entire drainage basin perspective of water systems. Water-resource systems and the numerous subsystems can be logically identified and incorporated into planning water quality control programs. This fact in itself provides a necessary basis to solicit accurate data and cooperation from the managers of _all_ facets of the water cycle (Welch, 1969). Intuitively, remote sensing of water systems does not necessarily become exclusive to water quality management.

If remote sensing is used for intensive studies, site selection for later routine ground monitoring will be tremendously refined. The true value of combining grab sampling and automatic monitoring with remote sensing will then quickly fall into proper perspective for use in state programs. At the same time, careful evaluation of data derived from all three techniques will contribute to the growing validity of using remote sensing as a _quantitative_ pollution monitoring device to later displace many laborious ground techniques.

Physical Basis for Remote Sensing

Remote sensing as a generic term consists of obtaining information in various portions of the electromagnetic specturm using mechanical, optical, and electronic apparatus at some distance from the target. Devices utilized for the collection of this information are broadly classified as either passive or active. Conventional aerial camera systems are by definition passive, whereas systems such as side looking radar (SLAR) are active types. Passive systems sense naturally emitted or reflected energy originating from solar sources or from the object itself. In contrast, active systems propagate energy signals which are in turn reflected by the object or scene and electronically recorded (Chandler, _et al_, 1970).

Every natural object above absolute zero temperature emits energy in a distribution as a function of its temperature and its wave length. Radiation laws describing the nature of this emitted energy are formulated with reference to a perfect energy emitter known as a black body (Wolfe, 1965).

As the temperature of a black body increases, the emitted energy also increases for any given wavelength. At the same time, the wavelength at which peak energy is emitted decreases with increasing temperature of the black body. Interestingly, the sun delivers its peak energy in a wave band width which corresponds to the visible range of 0.4μ to 0.7μ. A lower temperature black body, 200°K for example, delivers its peak energy at about 12μ or 13μ.

No real objects, with the possible exception of the sun which emits at about 6000 K, radiate energy as perfectly as a black body. By definition, a black body absorbs all energy incident on it and, conversely, the energy which it emits is the maximum possible at that given temperature and wavelength.

Therefore, the term describing this emitted energy--emissiveity (ε)-- is appropriately defined as unity, or 100 percent.

These non-perfect emitters, or "gray bodies", are described as a ratio of the actual surface emittance to the black body emittance at a given temperature and wavelength:

$$\varepsilon_\lambda \text{ f (wavelength)} = \frac{\text{N f(wavelength and temperature)}}{\text{B f(wavelength and temperature)}}$$

where N = real surface radiance or emittance; B = black body radiance at emittance at the identical temperature and wavelength; and ε_λ = spectral emissivity at a given wavelength.

Now, because of the small variation in radiance for a small wavelength band at a given temperature, the above relation also holds for small intervals of wavelength regions. The effect is, in essence, an average emittance for a small interval of wavelengths.

There are three other terms which describe the remaining properties of radiation. These three are:

ρ_λ - reflected energy or the surface property reflectivity

τ_λ - transmitted energy or the surface property transmissivity

α_λ - absorbed energy or the surface property absorbtivity

All these parameters are again a function of wavelength. By the conservation of evergy, the sum of these properties must be equal to the energy incident to a surface which is unity. This may be expressed in equation form,

$$1 = \rho_\lambda + \alpha_\lambda + \tau_\lambda$$

This sketch depicts the phenomena (Figure C-1).

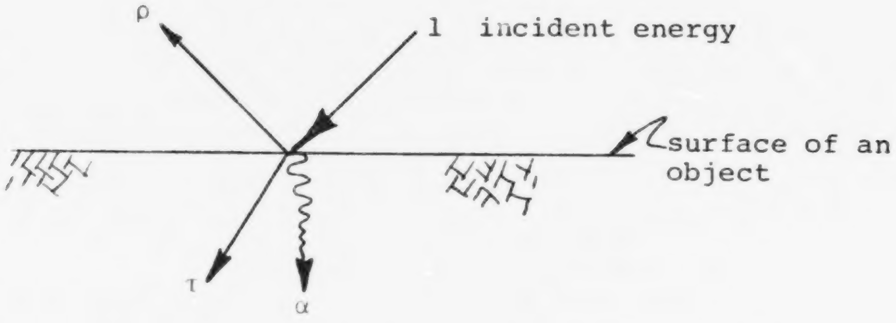

Figure C-1. Energy incident upon a surface.

For a black body, the transmissivity by definition must be zero, and Kirchoff's Law therefore applies and the emissivity must be equal to absorbtivity.

$$1 = \rho_\lambda + \alpha_\lambda$$
$$\text{and } \varepsilon_\lambda = \alpha_\lambda$$
$$\text{then } 1 = \rho_\lambda + \varepsilon_\lambda$$
$$\text{or } \rho_\lambda = 1 - \varepsilon_\lambda$$

Technically, these equations hold when no fluorescence occurs.

For each natural gray body surface, the total radiated power per unit of surface area is described by the Stefan - Boltzman Law:

$$W_T = \int_0^\infty \varepsilon_\lambda W_\lambda d\lambda = \varepsilon\sigma T^4$$

where W_T = total radiated power; ε = effective (or average) total emissivity, $\varepsilon = 1$ for a black body; σ = Stefan-Boltzman constant which is equal to 5.67×10^{-12} Watts/cm^2 - ^{0}K^4; and T = absolute surface temperature.

This total energy per unit of surface is actually the effective power delivered to a sensor which has been radiated from an object.

As previously discussed, energy sensed by passive remote sensing systems records energy emitted from an object or reflected by the object, which is primarily a function of the amount of solar energy the object receives. In a similar manner, active remote sensing systems record the energy propagated from the system and reflected to a recorder. In either instance, passive or active, the character of the surface governs the nature of the reflected energy.

All natural surfaces are described as bidirectional reflectors which are actually a combination of specular reflectance and Lambertain reflectance. Specular reflectance is primarily directional, such as would occur from concrete and water (Figure C-2). Lambertian (or cosine) reflectors return a diffuse or scattered energy form (Figure C-3). Bidirectional reflectors then combine the two, specular and Lambertian, to describe the manner in which energy is returned from an object or scene (Figure C-4).

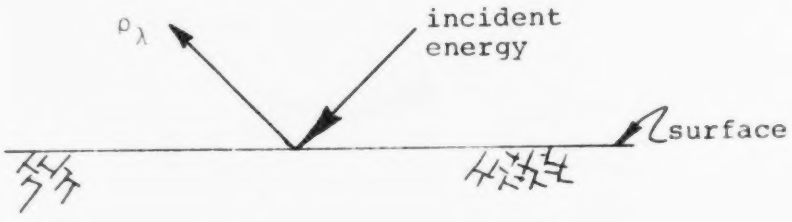

Figure C-2. Specular reflectance.

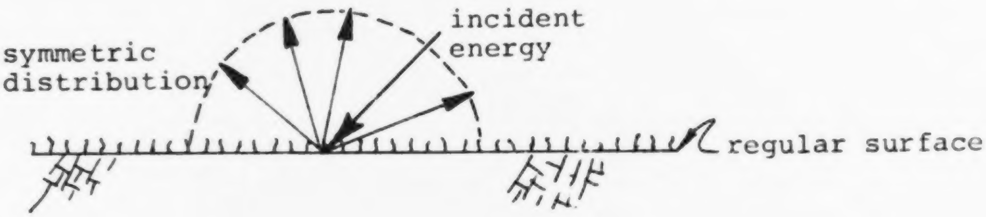

Figure C-3. Lambertian reflectance.

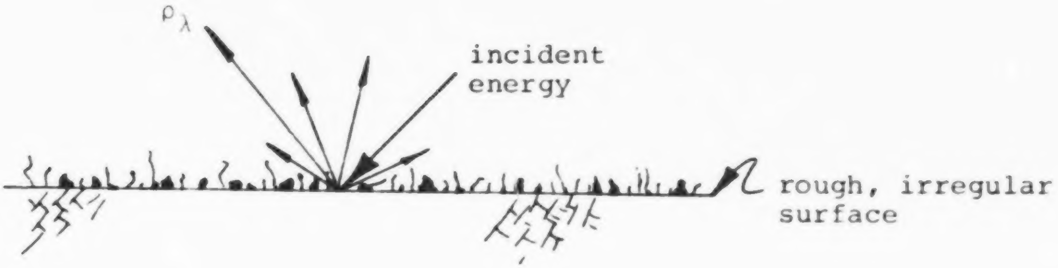

Figure C-4. Bidirectional reflectance.

In summary, our success in identifying a particular substance or pollutant is dependent on our ability to measure and detect all the above physical properties of that substance and interpret and decode the recorded energy.

The foregoing discussion was developed from Miller (1970) and Chandler, et al (1970).

Environmental Considerations

A record of reflected and emitted energy from a scene as sensed by an airborne remote sensing system actually depends upon the physical properties of the sensor, the intervening medium through which the energy must pass, and the target with its background. The most variable of these three factors are of course the intervening medium and the target's characteristics.

The intervening medium (air, water vapor, dust, etc.) scatter and attenuate the signal. The nature of the transmission of the sun's energy through the atmosphere has a crucial influence on the wavelengths of energy to reach the earth and, in turn, the signal transmitted back to the airborne sensor. In the ultraviolet region of the electromagnetic spectrum, atmospheric absorption of radiation is nearly complete out to about 0.3μ. Our small window in the adjacent visible region (0.4-0.7μ) is relatively free from absorption, but one must still cope with considerable scattering by atmospheric particles. In the infrared out to 25μ there are many absorption bands of water vapor, carbon dioxide, carbon monoxide, nitrous oxide and ozone. So complete is the absorption in some of these regions that they are for all practical purposes opaque. Absorption by water vapor virtually closes the atmosphere from 25μ to the more-or-less arbitrary start of the microwave region at 1000μ.

Figure C-5 depicts the regions of absorption and transmission for the various atmospheric constituents (Parker and Wolff, 1965).

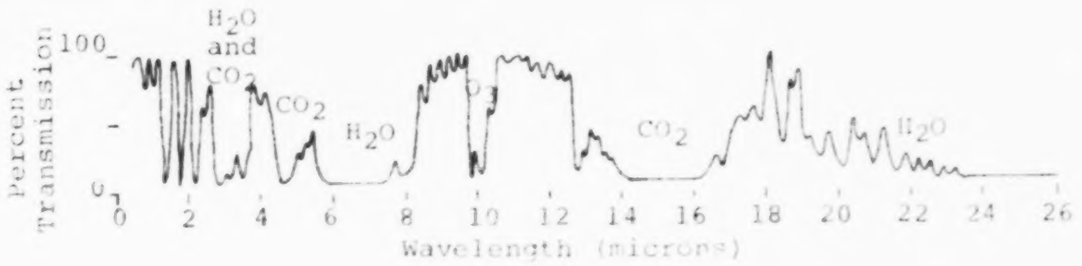

Figure C-5. Percent solar transmission as influenced by atmospheric constituents.

The target's physical characteristic is the second crucial influence on the signal received by a remote sensor. Most important of these characteristics is the emissivity (ε_λ) of the target surface. Every natural substance or combination of substances has a unique emissivity. Depending on the emissivity, the amounts of energy reflected or emitted (for a given wavelength) vary considerably. Our ability to distinguish substances remotely, then, is also subject to our abilities to distinguish between the effects of emitted and reflected energies.

Further, sky radiance, cloud cover, wind, and surface roughness modify various wavelength intervals of the target signal.

The emphasis of the discussion is to acquaint the reader with the myriad of factors which affect our ability to detect water quality conditions.

Remote Sensors for Spectral Regions

To this point, the characteristics of remotely sensed targets and the media through which the energies from those targets must pass have been discussed. The final topic of the physics of remote sensing is the actual description of the applicability of sensors to the various spectral regions.

Basically, there are nine regions of the electromagnetic spectrum. The reason for these divisions is primarily due to the types of sensors available for detection of energy within a spectral region. Technology has provided many means by which the interpretive powers of the eye may be aided and amplified. Parker and Wolff (1965) have made a simple description of these nine divisions and the classes of sensors which record in those ranges (Figure C-6).

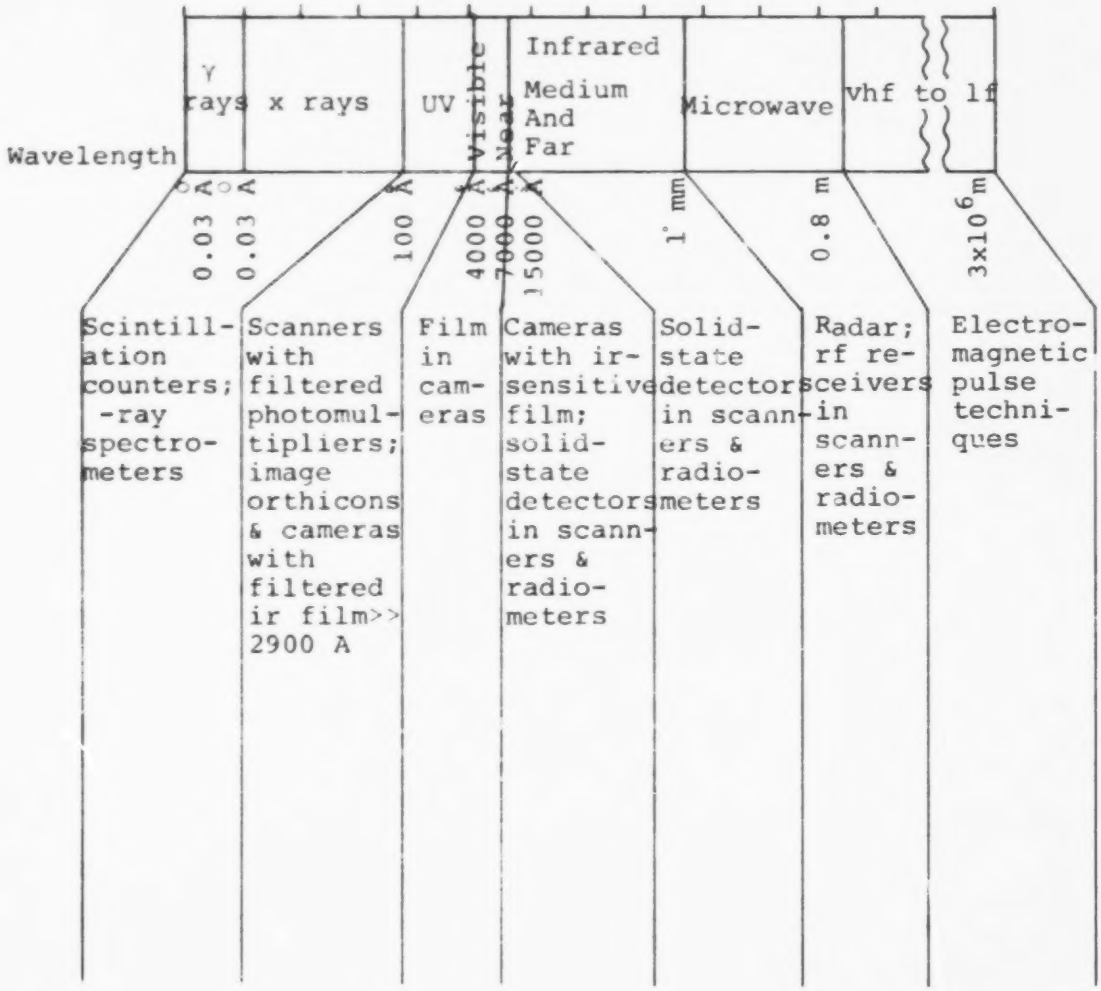
Wavelength
γ rays
x rays
UV
Visible
Near
Infrared
Medium
And
Far
Microwave
vhf to lf
0.03 Å
0.03 Å
100 Å
4000 Å
7000 Å
15000 Å
1 mm
0.8 m
3x10^6 m
Scintillation counters; γ-ray spectrometers
Scanners with filtered photomultipliers; image orthicons & cameras with filtered ir film>> 2900 A
Film in cameras
Cameras with ir-sensitive film; solid-state detectors in scanners & radiometers
Solid-state detector in scanners & radiometers
Radar; rf receivers in scanners & radiometers
Electromagnetic pulse techniques

Figure C-6. Remote sensors for the electromagnetic spectrum.

Due to the nature of electromagnetic radiation, obervational frequencies cannot be chosen at random. Nature dictates the spectral regions where the atmosphere will transmit sufficient radiation to the detector. Rabchevsky (1970, Part II) has described seven of these regions which may be applicable to use in water quality programs.

Low, Medium and High Frequencies (10^3-10^6cm). These frequency bands have been allocated primarily for communication services. Little has been done in utilizing this part of the spectrum for earth sciences investigations; however, considerable research is now under way in this area.

Very High Frequency (10^2-10^3cm). This frequency range is useful for remote sensing particularly because the size of the antennas is small enough to be practical for aircraft and satellites. The penetrability of ice at these frequencies is quite excellent, allowing profiling of ice cover over the ocean by utilizing the information from reflectors between the interface of ice and water.

Ultra High Frequency (10-10^2cm). This frequency range offers all-weather and system-size design advantages. This may be called a true microwave, all-weather, day-night band. The antenna size required, to produce a very narrow beam width for resolving earth materials, however, is still too large for installation on most aircraft and spacecraft.

Microwaves (Super High Frequency: 0.1-10cm). This has been the most active part of the spectrum for the design of searching, ranging, tracking, imaging and research-type radars. The low frequency of this spectrum provides all-weather advantages and the high frequency makes the design of small size, high resolution, antennas possible.

Infrared (0.7μ-1cm). All electromagnetic radiation is present not only in the infrared region, but also in the microwave and UHF regions, with sufficient intensity to be detected with appropriate radiometers.

Visible Spectrum (0.4-0.7μ). Photography is the most widely used method for remote sensing in the visible portion of the electromagnetic spectrum. Other promising devices for obtaining surface information are lasers, vidicon (television) systems, and optical-mechanical scanners and similar devices. One of the most promising techniques is splitting the visible portion of the spectrum into narrow multiple bands, by suitable filtering and recording techniques, using cameras and other above mentioned devices.

Ultraviolet (10^2Å-0.3μ). This is another area of increasing scientific interest for the study of surface materials. In this region greater than anticipated amounts of ultraviolet radiation may be recorded photographically or by optical-mechanical scanners.

Little evidence was discovered in the literature of the possible use of x-ray and γ-ray techniques for airborne sensing of water quality conditions.

Rabchevsky (1970, Part II) has condensed the methods of remote sensing, the corresponding working range, and the technique of application of the sensors into Figure C-7.

In conclusion, there are many single influences which affect the ability of remote sensing devices to depict water quality conditions. Basically, however, there are five physical considerations which must be made to optimize a remotely sensed signal (Hom, 1968) - the variability of:

1. the intensity of the spectral composition of the illuminant;
2. the reflectivity and emissivity of the target;
3. the sensitivity of the film or the sensor;
4. the transmissivity of filters used (optical or mechanical); and
5. the optical and electromagnetic effects of the intervening medium between the target and the remote sensor.

Applications of Remote Sensing to Water Quality

Before discussing the particular state-of-the-art water quality applications, a perspective in using remote sensing system to solve water quality problems will be reiterated. At the outset, the reader should recognize that remote sensing techniques are new and therefore have had very limited application and investigation relative to other monitoring techniques. This literature search has discovered no instances where remote sensing has been actually applied with success to solving a state water

METHOD	WORKING RANGE	TECHNIQUE
Scintillation Counters Gamma Ray Spectrometers (Geiger Counters, etc.)	<.03-100Å	Measurement of reflected/emitted natural radiation by means of characteristic response of detectors.
Scanners with Filtered Photomultipliers; Image Orthicons & Cameras with Filtered Infrared Film >2900 Å	100A-0.4μ	Records incident natural radiation by "Looking" at elements in sequence; Imaging ultraviolet spectroscopy.
Photography:		
Conventional Film (B&W, and Color)	4000-7000Å (0.40.7μ)	Wide Band Recording on emulsions; Converts small color differences to larger ones.
Infrared Film (B&W, and Color)	6000-9000Å (0.6-0.9μ)	Records absorption/reflection patterns on film.
Multispectral Bands	3000-9000Å (0.3-0.9μ)	Narrow Band Recording on emulsion.
Lasers	4000-7000Å (0.4-0.7μ)	Records backscattered radiation on photographic film and other media.
Photometers	4000-7000Å (0.4-0.7μ)	Narrow and/or wide band recording on emulsions and other media.
Spectrophotometers	In Any Spectral Region.	Narrow and/or wide band recording on film and other media.
Solid State Detectors in Scanners & Radiometers (Thermal Infrared)	1μ-1mm	Records incident natural radiation by "Looking" at elements in sequence.
Radars: Radio Frequency Receivers in Scanners & Radiometers	1mm-0.8mm	Records backscattered radiation; various media used for recording.
Electromagnetic Pulse Techniques (Sonar)	Sonic Waves 0.8-3x10^{6}mm	Measurement of pressure waves reflected from terrain or objects (primary use in water).
Geophysical:		
Gravimeters	Gravity Field	Measurement of acceleration of gravity.
Magnetometers	Magnetic Field	Measurement of "local" magnetic induction.
Seismographs	Sound Waves	Measurement of elastic waves in earth.
Electric Logs	Electric Field	Measurement of electric properties of subsurface geologic formations.
Geochemical	Chemical Reactions	Measurement of relative and absolute abundances of the elements in the earth.

Figure C-7. Remote sensing methods.

quality problem. To be sure, there are a number of applications, particularly at a research level, which give great promise of being applied to state problems. Nowhere was there indication that aerial remote sensing techniques are being applied on a regular basis for data acquisition in any state program.

Therefore, to build a framework which places the use of remote sensing in proper prospective is crucial to considering its potential. If the reader tries to conform remote sensing to the traditional basis built around the abilities of grab sampling and automatic monitoring, the benefit of the following discussion will be greatly diminished.

In other words, the reader should not ask himself questions like: Does remote sensing provide dissolved solids information in parts per million? or Does remote sensing provide an exact pH reading? The reader should, however, begin to consider questions such as: Since remote sensing can locate the distribution and relative concentration of an effluent plume in a stream, where can grab samples best be taken?

A simple analogy at this point will point up why remote sensing is difficult to compare, in terms of quantitative information, to grab sampling or automatic monitoring. Every individual is equipped with a very precise remote sensor--a pair of eyes. We use our vision to give us a rapid, spatially large, evaluation of a given situation. For example, we wish to know if a pot of water on an electric stove is hot and how hot it is. We know from experience quite a number of prarmeters which will provide this information by using our eyes only. First, we see the pot on the right-front coil. Immediately, we know not to consider any other coils. Next, we see that the control knob labeled "right front" is positioned on a "high" setting. Again, we need not consider any other knobs, and we may infer the possibility of the water in the pot on the right-front coil to be potentially hot because of the setting. Further, if we know how long the pot has been on that coil and how much water is to be heated, we have a much better chance of inferring the water's temperature at that moment. Also, if we know the water's previous condition prior to being in the pot, whether frozen or boiling, our chance for accurate inference increases. Going further, we "see" (or remote sense) that the water is giving off steam, the water is highly agitated, and the coil is glowing red. From our previous knowledge and experience of the fact that we are at sea level and water boils at 212°F at that altitude, we may very accurately infer the water's temperature is very close to 212°F. The water is therefore hot!

Of course, we don't go through such a detailed deductive process in real life, but we see the value of not actually having to measure a given parameter by contact. The information we derive from our eyes is not in itself quantitative, but our inference from decinding first what we want to know and second, what factors indicate what we want to know, provides us with a quantitative, accurate answer.

In a similar manner, when put in the context of the "eyes" analogy, remote sensing may provide overall perspective and information not available from other techniques. For example, if a color infrared photo reveals a healthy bed of underwater plants, we actually know a great deal more than that fact. The presence of those plants indicates fairly high dissolved oxygen content, a tolerable pH range, low sediment or settleable solids load (that is, the silt is not blocking the light), and the absence of choking bottom sludge or undegraded material competing with those plants for oxygen.

Ground knowledge of plant varieties may indeed delimit the range of these mentioned parameters and further aid our data collection.

A color photograph of a scene is another example of the use to a water manager. For example, the fact that water is brown, indicating a turbid condition, may be sufficient knowledge to answer a question of whether or not a farmer is using poor irrigation practices as indicated by a muddy surface return flow to a river. The fact that water has 2000 ppm settleable solids, or 2750 ppm settleable solids is immaterial to answering that question. In another application, a parts per million determination may be crucial. By using remote sensing in this case, the expense of a lab sample has been saved.

In summary, it is difficult to compare the value of remote sensing, in terms of quantitative information rendered, with information provided by grab sampling and automatic monitoring techniques. The question, stated negatively, then becomes, what information will remote sensing provide that the others cannot. Thereupon, the dollar-cost evaluation comes into proper perspective. Therefore, the water quality manager must decide which techniques will provide at least costly information necessary to solve a water quality problem within corresponding space and time constraints.

In the previous section, the various remote sensors for wavelength regions in the electromagnetic spectrum were discussed. The state-of-the-art applications for these various spectral regions will now be generally discussed in order of increasing wavelength. The discussion for each region is determined by appropriate investigations found in the literature search.

The following regions will be discussed:

1. Visible Region .4-7μ;
2. Thermal Infrared Region 1.0-14μ;
3. Microwave Region 0.1-10cm; and
4. Multispectral Sensor Systems

Visible Region (.4μ - .7μ, photographic)

Silvestro (1969) has demonstrated that quantitative concentration distributions of particular pollutants can be constructed from repeated microdensiometer scans parallel and perpendicular to the shoreline of a river-pollutant plume situation (Figure C-8). Silvestro examined two categories of pollutants - molecular and particulate (including algae). He examined each category at a theoretical,

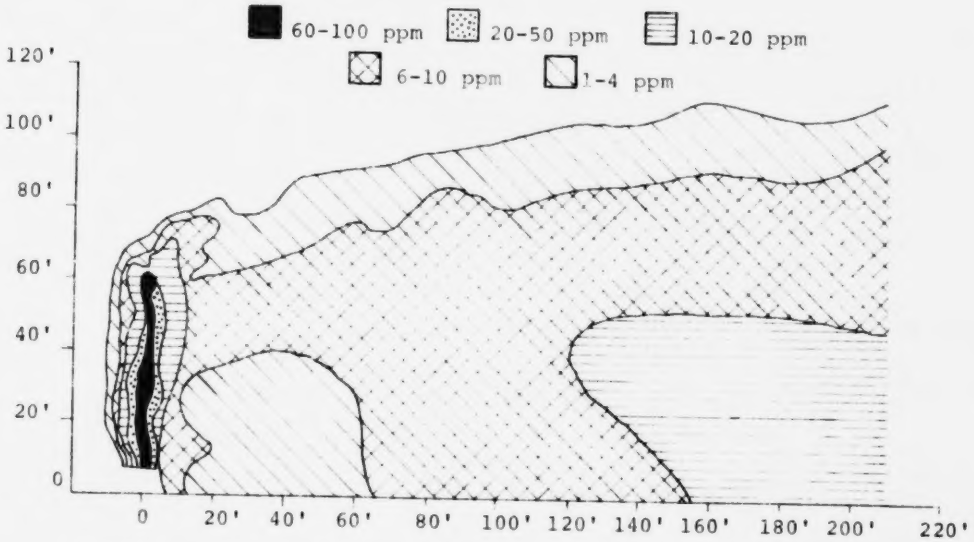

Figure C-8. Iso-concentration map of effluent flow under rough water conditions. (After Silvestro, 1969) laboratory experimental, and field level. The spectral range of his investigation included 0.3μ to 0.9μ and ten distinct channels (spectral bands) in the visible range. His investigation revealed that ambient light used for imaging water and water contaminants reaches the camera primarily by the scattering mechanism. Sunlight is scattered into the camera by the solution and thus scattered light is the imaging light. Silvestro also resolved that the concentration of phytoplankton density generally increased reflectance significantly in the 0.6-0.7μ range.

Silvestro concluded that the applicability of aerial remote photographic systems is dependent on the two following considerations:

1. Do pollutants and water quality parameters affect light (energy) sufficiently to extract the desired information; and
2. Can remote sensing techniques be combined with analytic procedures to extract the available information?

Wezernak and Polcyn (1970) have demonstrated on a gross basis, that Silvestro's first condition is widely true. Figure C-9 demonstrated for roughly over the same spectral interval, that significant differences do exist between water bodies and types of pollutants in general. Specifically, spectral differences exist for suspended solids concentrations.

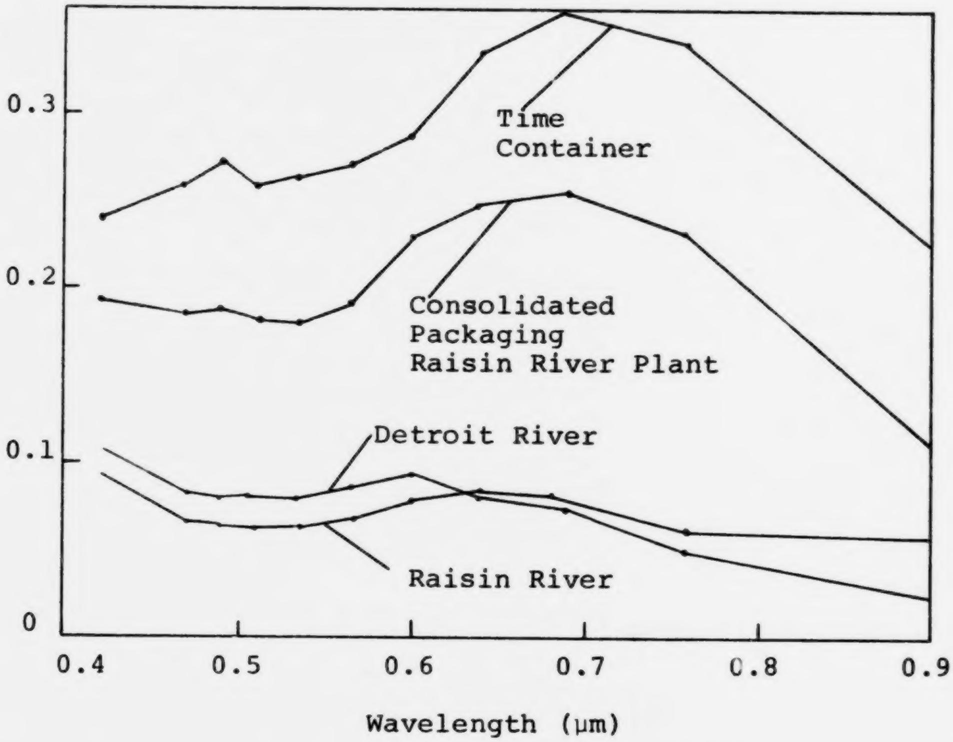

Figure C-9. Spectra comparison: Raisin River.

Scherz, Boyle, and Graff (1969) lend further support to Silvestro's findings. These authors studied five classes of fluid wastes; namely, corn cannery waste, milk waste, municipal sewage, tannery waste, and sulfite liquor and percent solids. Their findings show, for example, that at 0.2μ differences in percentage reflectance are about 4 percent between municipal sewage and milk waste, while differences are about 48 percent between milk waste and cannery waste. Differences in spectral signatures are the keys to distinguishing between pollutants.

Further, these investigations recorded the variation of the reflectance of distilled water with temperature over the visible range. They reported, for example, that at 0.5μ, the reflectance for 7°C water is about 10 percent greater than is 83°C water, while at 0.35μ, their reflectance characteristics are identical. Unfortunately, the authors found that lab methods may not correlate well with field studies. Various film-filter combinations were studied, with no combination apparently best for all cases for depicting fluid wastes.

Cooper (1969) used two types of color film to study the characteristics of water quality. Kodak color infrared film type 8443 detected algal growths with ease along river beds. In some cases, acid stains showed brilliant green along the shoreline through a moderate tree canopy. Ektachrome MS film did not depict these phenomena. In some cases, low pH (3.5-4.0) was a definite green to blue green. Other streams with comparable pH showed blue-green to light blue. Correlations were attempted and these results were identified with a "Craftint Color Match Designer's Color Pack" selection of 219 colors.

Schneider and Kolipinski (1969) have also used color aerial photography to identify the pH of a water body. They concluded that color aerial photography is useful in identifying some pollutants in streams. Streams polluted by acid mine drainage can be identified on color photos by bright orange ferric oxide. The acidity of the stream can be inferred. The pH above the deposits will be acid with iron in suspension. With mixing in the region of the deposits, the pH is about 6.0 where it meets with relatively alkaline waters.

Thermal Infrared Region (1.0μ - 14μ)

The basic physical considerations for detection of pollutants within the thermal infrared region are similar to considerations other regions. Colwell (1967) suggests, among others, the following considerations:

1. Objects on the surface of the earth receive most of their radiant energy from the sun (therefore, time of day is crucial to the interpretation of the data);

2. Various spectral zones of spectral bands are recognized within the electromagnetic spectrum;

3. Different objects reflect, absorb and re-emit energy to differing degrees in various spectral zones;

4. The earth's atmosphere (primarily the CO_2, O_3, and H_2O molecules) selectively absorbs certain wavelengths of energy emitted by the sun which create "atmospheric windows" where energy of certain wavelengths passes freely;

5. The 8μ - 14μ range is one such window called the "thermal infrared." In this region, the reflectance is low and the emissivity high. This is a fact which contrasts with the "photographic infrared" (0.7μ - 1.0μ range) which has the property of high reflectance and low emissivity; and

6. The 3μ - 5μ region is characterized by reflectance and emission being about equal.

Thermal infrared scan systems can locate thermal anomalies day or night. A thermal infrared record in conjunction with other records, such as aerial photography, is a valuable supplement to measuring specific phenomena. Some of the most valuable information is obtained by acquiring records simultaneously in two or more wave bands. For example, the 3μ - 5μ band with one sensor and the 8μ - 14μ band with another sensor (Colwell, 1967).

Richards and Massey (1966) installed an infrared thermometer (IRT) on an aircraft as an airborne radiation thermometer (ART) and subjected it to a program of test and evaluation as an instrument for measurement of surface water temperatures in the Great Lakes area. The first phase of the program dealt with the mounting and exposure of the sensor. The second phase, in conjunction with the research vessel "Porte Dauphine," dealt mainly with operational and theoretical aspects of the technique.

With some limitations, it was found that the ART provides a good method of making fast and reliable water temperature surveys. The present instrument and installation produced an absolute accuracy of the order of 1.0°C and a relative accuracy within 0.5°C.

Using a similar system of instrumentation, Van Lopik, Rambie, and Pressman (1969) concluded that airborne infrared mapping systems, operating in the 8μ - 14μ portion of the electromagnetic spectrum, provide a capability for rapid surveillance and monitoring of water-surface temperatures. Specific applications include (a) determination of thermal circulation and diffusion patterns produced in water bodies by coolant discharge from power plants, (b) assisting in the development of a thermal pollution index based on aerial thermal data and water body dynamics/variations, (c) detection of thermal pollution and measurement of river temperature and temperature decline downstream from surface and subaqueous heated water discharge, and (d) establishment of natural seasonal and diurnal ranges of water-surface temperatures before construction of plants that will produce liquid effluents. One approach to the problem involves identification of temperature-independent emissivity properties and relationships and aerial recording of energy levels within selected narrow bands which adequately characterize 4μ to 14μ emission curves characteristic of pollutants.

Microwave Region (.0cm - 10cm)

The use of remote sensors in the microwave region has shown some prospect as an indicator of water quality conditions. Rabinovich, Shchukin, and Melent'yev (1966) successfully used radiometric equipment in the 3cm range to measure the temperature of the water surface. Ground truth data was taken simultaneously with remotely sensed data, the average difference between the two being only 0.3°C. The mean square error of measurements with respect to average temperature was 0.7°C. They concluded that information may be taken through clouds and precipitation, interference decreasing with increasing wavelength. Use of the 8cm - 10cm range almost eliminates interference from the atmosphere and clouds.

Aukland and Conway (1969) successfully used the microwave region to detect the extent and thickness of oil slicks. Examination of the theoretical and experimental body of information that is presently available leads to the conclusion that there are two mechanisms by which the presence of oil on a water surface may be detected. Both of these mechanisms create an apparent temperature anomaly when oil is present.

The first phenomenon to be considered is measuring the local change in sea state due to the presence of the oil pollution. This phenomenon presents very strong signals to microwave radiometers when winds of 6 knots or more are blowing. It is felt that this will be the primary detection mechanism for thin oil films. The second mechanism to be considered is the direct change in the emissivity of the water surface due to the presence of oil. This phenomenon is slightly the weaker of the two but offers the promise of measuring oil thickness. Because of the independence of these two potential detection mechanisms, they are described separately in the following paragraphs.

The effects of oil slicks upon sea state were difficult to determine in measurements from pier installations, as the oil was often accompanied by detergent foam and debris. The presence of foam caused an increase in radiometric temperature, instead of the decrease expected from oil alone calming the water. For relatively calm seas with wind ripple, radiometric temperature decreased by approximately 4°K. In higher sea state, decreases up to 10°K occur. When oil film becomes thick, the apparent temperature increases due to the dielectric layer on the water surface. Thick films caused signatures of up to 100°K at 1.0mm thickness.

Aukland and Conway concluded that microwave radiometers can detect oil spills on water day or night. Care must be taken when these techniques are applied since oil thickness, incidence angle, and wind speed could render spills undetectable.

Multispectral Sensor Systems

Wezernak and Polcyn (1970) present a good system description and discussion of design capacity for the multispectral system. The passive multichannel scanner system is capable of sensing reflected and emitted energy simultaneously in a number of narrow spectral intervals in the ultraviolet, visible and infrared region of the solar spectrum. The system basically consists of a spectrometer for dispersing the radiation spectrally and filtered detector arrays placed at the focal points of a double ended optical-mechanical scanner. Figure C-10 shows schematically the system operation. The scanner uses reflective optics to collect energy over a wide spectral band between ultraviolet and

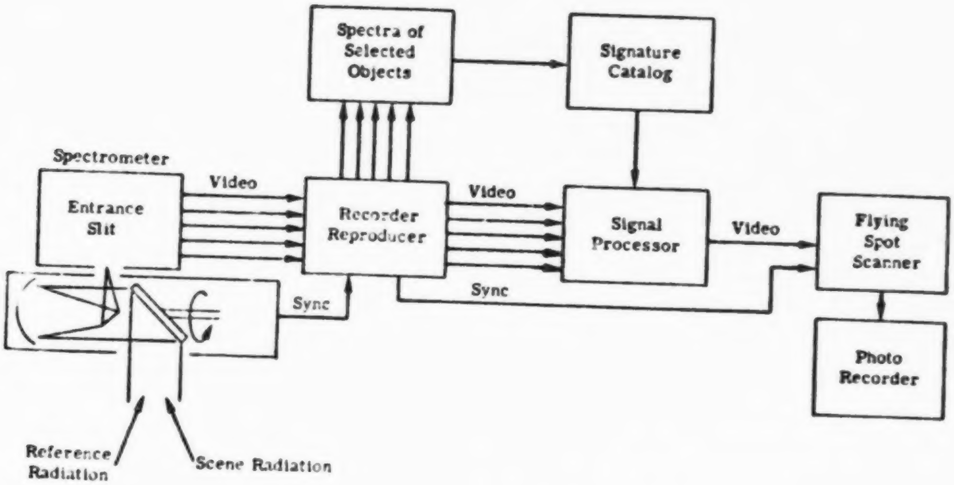

Figure C-10. Schematic of multispectral scanner and data processor.

thermal infrared. The entrance slit of the spectrometer is placed at the focal plane of the scanner to insure that space and time simultaneity is achieved for all channels between .4μ and 1μ. Filtered detectors for the infrared region and the use of short electronic time delays provide coincident data for the region beyond 1μ. Additional detectors and filters can be provided for the ultraviolet region. Signals from the detectors are stored on magnetic tape for later image reconstruction and data processing. As an integral feature of the system, reference lamps, an input proportional to the sun energy, and adjustable temperature plates are viewed each revolution of the scanner mirror. Thus, for the first time (with an optical-mechanical scanner) reproducible data can be obtained which is referenced to known radiation sources and is capable of accounting for changes in solar illumination. These controlled points in each scan line permit the use of sophisticated electronic pattern recognition techniques with both analog and digital computers (Nalepka, 1970).

The generation of a spectrum for each element permits machine recognition of classes of objects whose spectral characteristics are similar within certain electronic decision levels. In the field of water pollution control, it is believed that remote spectral measurements can be used to detect and identify effluent discharges.

In order to determine spectral characteristics, the airborne data recorded on magnetic tape is electronically digitized and then stored in a computer. The analog to digital converter consists of a high accuracy (13 bit and sign) successive approximation converter capable of providing samples in 10 microseconds. The data is formated and coded into 48 bit words for a CDC-1604 computer. Special computer programs have been written to edit the digital tapes and format the data for use with FORTRAN programs. Selected portions of the objects mapped are used as training areas for which the spectral characteristics are computed. Once computed, a computer generated spectral curve can be made that is referenced to the incoming solar spectrum or to other objects in the scene. In some cases, ground reflectance standards are used to provide absolute reflectance calibration.

The spectral properties are then available for use with the computer to perform spectral matching operations to enhance the detection of selected objects of similar properties or to map the different concentrations of an effluent

The electronic format of the data also permits a voltage sampling operation (for any selected band) in order to display small density differences. For example, the mixing zones of a thermal discharge into a river or lake can be studied readily by quantizing the data in the 8μ - 13.5μ band into one-half degree steps, color coding each step, and combining the set into one color composite display. Each color represents the isotherm for a chosen temperature level. The use of two adjustable reference plates in the scanner system insures optimum recording and accurate reconstruction of the apparent temperature pattern.

Many other computer programs have been devised and are employed in processing the multispectral data for particular applications.

One technique which is certain to be used extensively in the future for noncontact data acquisition involves analysis on the basis of fluorescence. This analytical technique could be used for the detection and identification of subtances such as rhodamine dye, chlorophyll, lignin-sulfonates, and many other substances which possess the property of fluorescence. Recent reports which describe the Fraunhofer line discriminator (Stoertz, et al, 1969) and laser induced emissions (Hickmann and More, 1970) indicate that airborne fluorescence measurements are feasible.

Carnes (1970) has spoken to the applicability of multispectral scanning for solving water quality problems. Carnes separates water pollutants into four categories:

1. thermal;
2. nutrient;
3. chemical; and
4. petro-chemical (oil)

Each pollutant has a spectral signature which may, or may not, be capable of detection. He views the detection of these four categories of pollutants as dependent on these four facts:

1. Thermal maps show anomalies and pollutants have categories, or thermal anomalies;
2. High nutrient concentrations have point sources and an exothermic effect;
3. chemical pollutants are point sources and are usually a different temperature than receiving waters; and
4. Oil slicks inhibit evaporation, which produces a warmer apparent temperature than surrounding waters.

Carnes points out that the primary pollutant is not always, of itself, the agent that damages ecology. Similarly, the primary pollutant may or may not provide the remotely observable effect which permits detection.

Lowe and Hasell (1969) observed the Santa Barbara oil spill with multispectral equipment and determined the slick was best detectable in the ultraviolet and thermal infrared ranges.

Costs of Remote Sensing

The cost of remote sensing systems is perhaps the most elusive aspect of applying such methods in the field. As was previously discussed in the earlier portions of this report, the expense of a remote sensing application is entirely dependent upon the needs and goals of the undertaking. However, to present the reader with a perspective on the costs, the following discussion will identify the possible latitude of cost and present the few specific costs available.

Sensing Equipment

A tremendous range of expenses exists for remote sensing instrumentation. Simple systems, such as hand-held common 35-mm cameras with a two place, single engine aircraft, may be as low as $30 - $40 per hour (Cooper, 1969). However, this makes absolutely no account for interpretation of any kind, nor does this account for the quality or quantity information produced.

In contrast, a sophisticated aerial photo system, like the one at Colorado State University, is quite a different story. This flight facility and interpretive laboratory utilizes the Wild RC-8/6 inch Universal Aviogen Lense with automatic trip and roll compensator. This camera, in combination with the twin Beechcraft Aero-Commander 500-B research aircraft, produces a 9 x 9 inch high-resolution photograph of incomparable quality. Interpretive devices include a Kelsh Plotter and a Wild STK-1 precision stereocomparator/digitizer/IBM card punch. Cost of the flight facility including pilot and operator with film, instruments and supplies is about $200 per hour. A CDC 6400 digital computer is available at an additional cost of $430 per hour. Photointerpretation with this facility costs roughly $16 per hour.

For emphasis, it must be reiterated that information needed and degree of interpretation dictate cost.

Radar and scanning-spot systems (thermal infrared) may have a cost magnitude of $300 per hour for flight facilities and equipment, alone. Interpretation or image enhancement costs are additive to flight costs.

Application of Remote Sensing Systems to State Programs

As an introduction to the actual form that a remote sensing program might take at the state level, an investigation undertaken by Neumaier and Silvestro (1969) will be discussed at some length. The purpose of their investigation was to show how remote sensing can be used as a tool for detecting water pollution, both qualitatively and quantitatively.

In a program sponsored by the New York State Conservation Department, laboratory experiments were performed to determine the spectral characteristics of effluents from a paper industry, an oil industry and a sewage plant. These data, along with theoretical studies, were used to extract the desired information from multiband aerial photographs taken over these discharges. The techniques employed allow estimation of pollution concentration in a number of cases.

The study was undertaken in three stages. The first stage made a qualitative assessment of the potential of spectral photography for detection of effluents. The second stage performed laboratory experiments to determine the characteristics of reflected signals from pollutants. In the third and final stage, laboratory information was implemented in field studies, with mathematical and physical relations being developed to describe the nature of light reflected from molecular and particulate pollutants.

The carry out the qualitative phase of the study, 22 miles of shoreline along the Niagra River and Buffalo Harbor were photographed by an aerial system. Twelve-hundred photographs were taken in five narrow bands plus color photos. Seventy-four waste discharges were located. Twenty discharges were enhanced in at least one photographic band, while fifty of seventy-four had improved contrast. Detection of pollutants could be improved by selection of band widths.

The laboratory phase was then carried out. The spectral signatures of different industrial effluents were examined with a spectrometer over the entire visible spectrum at different concentrations and depths with various external illuminating conditions. The spectral reflectance characteristics of discharges from an oil refinery, a paper mill, and a primary treatment plant were measured at five concentrations and at least six different depths.

The final field measurements revealed some significant statistics. Neumaier and Silvestro stated with 90 percent confidence that the precision of the photographic system (versus ground data) was ±6 percent. Quantitative information for pollution studies not easily available by other means can be extracted from aerial photos. High potential exists for the application of color photography to identifying water pollutants.

Neumaier and Silvestro reached a significant conclusion. In order to use aerial photography for quantitative measurements, rigid controls must be maintained. Film history must be noted before processing. Film must be calibrated with gray scales of know density. A computer program is used to obtain corrections for variations in exposure with position in the format, variations in filter transmittance with wavelength and viewing angle, camera flare, and transmission factors of the atmosphere. In addition, the signal detected from the air varies with surface characteristics of the water, type and concentration of pollutant, nature of the bottom, depth, irradiance, wavelength, the angle of illumination, and the observation angle. When all these factors are taken into account, quantitative aerial data can be obtained which is repeatable and accurate.

Further, the behavior of the effluent plume, as determined from a quantitative analysis of aerial photography, can be used to determine mixing characteristics of receiving waters. Contours of pollutant concentrations may be plotted manually or automatically by microdensitometer scans parallel and perpendicular to the shoreline.

The techniques used in the preceding study conducted by Neumaier and Silvestro is indicative of the thinking necessary to use remote sensing in state programs. Since states have some form of ground monitoring systems, the correlative field data for many potential application is already established.

Water uses vary considerably throughout the United States. For this reason, the particular water quality requirements for the states are difficult to quantify in terms of use. In this light, a general discussion of how remote sensing could be used in state water quality monitoring problems would have little specific value for designing programs. For example, Colorado would have little interest in water quality criteria for protection of shellfish, whereas Hawaii would have little concern over stream quality when all the water is diverted for irrigation. On the other hand, quality of drinking water supplied by wells would be common to both states' interests.

So then, in discussing the applicability of remote sensing to state water quality programs, the emphasis must be on techniques of data acquisition, and the application will be dependent on the imagination of whoever designs the program. In order to present the breadth of possible water quality problems throughout the states, Oswald (1969) has developed a table of water quality criteria versus water use (Figure C-11).

Figure C-11. Quantitative estimates of water quality criteria for water resources.

Use Criteria	Drinking	Industrial	Agricultural	Swimming	Recreation	Fish & Wildlife	Shellfish
Epidemiological (E. coli MPN)	<1.0 org/100ml <10% of 10ml Portions Examined per Month	Depends on Industry	Low for Truck Crops	240-2400 org/100ml 20% N.T.E. 1000	100-5000 per 100ml*	None	<70/100ml OK 70-700/100ml bad >700/100ml Impossible
Dissolved Oxygen D.O.	Adequate to Prevent Odors 5-10 mg/1	Nill for Boiler Feed Water	Must not Deplete D.O. in Soil	Adequate to Prevent Odors	Adequate to Prevent Odors	5 ppm or Greater, Depends on Species, pH, Temp.	Never Totally Absent, 2-5 mg/1 min Depends on Temp.
pH	0.8-7.2 OK up to 8.0	6.8-7.2 Process Dependent	None	6.5-8.5 Some Alk. takes up to 10	6.5-8.5	6.5-8.5 Depends on Species, D.O.	6.5-8.5, Depends on Species
Biochemical Oxygen Demand (BOD)	<2-3 mg/1	Low, Depends on Industry	Low to Prevent Loss of D.O. Soil Sour or Clogging	Low Enough to Maintain D.O.	Low Enough to Maintain D.O.	Low Enough to Maintain 5 ppm D.O.	Low Enough to Maintain D.O. Prevent Closeup
Algal Growth Potential (AGP)	5-10 mg/1	5-10 mg/1	50 mg/1	10-20 mg/1	10-20 mg/1	<20 mg/1	<20 mg/1
Grease & Floating Solids	None Allowable	Low	Low to Prevent Soil Clogging	None Allowed	Low, Wild Fowl Protection	Low, May Limit Oxygen Transfer	Low to Prevent Gill Clogging
Turbidity (Non-biological)	None Allowable	Usually None	Not too Important	Low to Permit Light Transmission	Low to Permit Light Transmission	Low to Prevent Silting or Gill Obstruction	Low to Prevent Silting or Gill Obstruction
Color	None Allowable	Depends on Process	Not too Important	Should Not Absorb Light	Not too Important	Not too Important	Not too Important
Temperature	10-20°C	10-20°C	Not Important	30-35°C	25-30°C	5-20°C	8-15°C
Toxic Materials	None Detrimental to Human Pb, NO_3^-, CN, F, Zp Heavy Metals	Depends on Process	Low Monovalent Cations Low Boron	None Detrimental to Humans	None Harmful to Equipment Acids, etc.	Cu-0.001 ppm H_2S-0.05 ppm CR-0.05 SO_4^-S Cl_2-0.3 Phenol 0.1	Very Sensitive to Org Acids Cu, CR & High Bacterial or Algal Populations

*California Board of Public Health STDS for Water Contact Sports - Salt Water
1. No more than 10% of samples in one month in excess of 1000 MPN
2. No single sample in excess of 10,000 if confirmed by duplicate sample within 48 hrs.

There have been a number of applications of remote sensing techniques throughout the United States. Many of these applications have potential for wide-spread use in state programs of specific types. The salt-water marsh mapping studies in North Carolina would have application to most coastal states, for example. The following paragraphs discuss a variety of present state applications.

Schneider and Kolipinski (1969) have applied color photography to locating fresh water springs which produce turbulence in offshore sea areas. In a North Dakota study, species of grasses served as indicators of salinity in potholes. Further, color photos of the Great Salt Lake yielded sediment circulation and movement. In still other studies in the Florida Everglades, photos revealed inland penetration of salt water. There existed a marked change in flora from fresh to salt water.

Stroud and Cooper (1968) mapped in North Carolina relatively pure stands of salt marsh vegetation with color photographs. Many states have coastal estuaries which could be investigated by such techniques.

Lipley and Palmer (1967) successfully used remote sensors to locate off-shore fresh water springs in the Hawaiian Islands. In this project, spectral photography and infrared thermometry are being evaluated as sensors to develop inexpensive and reliable methods of detecting and measuring these springs. Photo techniques did not yield specific results.

Coastal springs are anticipated to be particularly amenable to detection and mapping by synoptic sensors due to the large surface salinity and temperature anomalies found in field investigations. The infrared thermometer is applicable to location of some coastal springs.

Some of the suspected physical differences between spring water and sea water supporting the search for instrumentally detectable optical contrasts are, according to Lepley and Palmer (1967):

1. Fresh water contains different dissolved and suspended organic matter, i.e., tanning dyes from land vegetation in fresh water as opposed to yellow "gelbstoff" from chlorophyl-bearing phytoplankton in sea water;

2. Spectral interference effects from thin organic films on either water surface may be especially detectable in the near infrared (visible sea slicks from such films are known to sometimes align themselves with subsurface water

structures, such as internal waves);

3. Exsolving gasses bubbling from cold floating spring water warmed by sea water may throw small droplets of water into the air. This effervescent mist may be detectable by its scattering of infrared light (an infrared "fog" layer);

4. Capillary surface waves on the sea water surface may be smoothed by the spreading surface layer of fresh water. The consequent modification of surface-reflected skylight caused by the smooth surface can be enhanced by a comparison of images photographed through polarizing filters at various orientations.

Howell (1969) has successfully conducted airborne measurements of relative humidity, temperature and air currents. These data are telemetered to a ground-based station and recorded. A radar unit tracks the aircraft and electronically plots its position on a base map of the area being studied. Thus, the distribution of atmospheric conditions can be directly related to the underlying terrain and vegetation features. Consequently, such systems could be indicative of large scale water quality features in the states.

Application of remote systems has been made in California. Studies were conducted at Lake Tahoe, La Jolla, San Diego Bay, and the University of California at Davis Campus. Sea dyes were evaluated for tracing tidal and current movement by multiband and color aerial photography. Preliminary studies were made into depth penetration capabilities of aerial photos for mapping and identifying aquatic vegetation and bottom sediments. The studies identified black and white spectral bands useful for tracing Rhodamine dye and evaluating sediment conditions. The studies indicated that color film was more convenient to use than multiband photography for water studies (Welch, 1968).

State Application of Satellite Programs

Imagery taken by existing and proposed satellite reconnaissance programs may provide a valuable input to the remote sensing programs within the states. Jamison (1970) reports that the utility of the proposed Earth Resources Observation Satellite (EROS) Program as an information source for operational state agencies and academic institutions has been explored in a one-year study within the State of

Washington. Operational personnel from most natural resources and land use oriented state agencies participated in the project. Research personnel from the two major state academic institutions (University of Washington and Washington State University) carried out studies of the imagery.

High altitude, small scale photographs, both singly and in mosaic form, were used to simulate Earth Resources Technology Satellite (ERTS) imagery. Participants were asked to relate their data needs to the proposed ERTS imagery and the timeliness of Satellite surveillance.

It was found that significant use of ERTS-A imagery can be made by state agencies and researchers at state educational institutions within the State of Washington. Without question, additional uses for the imagery will be discovered when the actual satellite images become available and a cost is known. One major new use to be anticipated, if the cost is low, is reducing the expense of existing methods of field surveys by directing sampling only to areas with a high probability of a change of specific interest. Another major use is the acquisition of data (such as snowline and rate of melt) that has, heretofore, been difficult or costly to obtain.

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APPENDIX D

COLORADO'S STREAM CHARACTERIZATIONS

The following river basin descriptions and data summaries represent the stream characterizations utilized for this study. The Arkansas, Colorado, and South Platte Rivers have a subsection presenting their data. The other rivers are covered in a final subsection.

Arkansas River Basin

The upper Arkansas River Basin lies entirely within Colorado where it drains approximately 26,140 square miles. The river runs through Colorado for approximately 350 miles and its maximum drainage width is 170 miles.

The Arkansas River begins in the Rocky Mountains near Leadville at an elevation in excess of 13,000 feet. It flows south by Buena Vista and Salida, turns east just after Salida, emerges from the mountains near Canon City, enters the high plains at Pueblo, and, if the water escapes being used for irrigation, it leaves the state near Holly. Below Pueblo the major tributaries are Fountain Creek, St. Charles, Huerfano, Apishapa, and Purgatoire Rivers. John Martin Reservoir is located on the main stem just below its junction with the Purgatoire River.

In the mountain headwater region of the Arkansas River, the precipitation averages over 20 inches per year, while downstream from Pueblo in the high plains the rainfall averages less than 15 inches per year. The water originating in the mountains is the result of light rainfall or melting snow, while on the plains intense rainfall produces flash floods and intermittent stream flow.

Arkansas River water in Colorado is used primarily for irrigation, municipal and industrial water supplies, and for recreational purposes. Limited water supplies in the basin have resulted in water being imported from the western slope of Colorado. This indicates the importance of water quality control in the Arkansas River Basin.

Water quality of the main stem of the Arkansas River is characterized in Figures D-1, D-2, D-3, and D-4. Figure D-1 is a composite, while Figure D-2, D-3, D-4 illustrate the variations. Data for these graphs is given in Table D-1. Table D-2 contains similar data for the tributaries of the Arkansas.

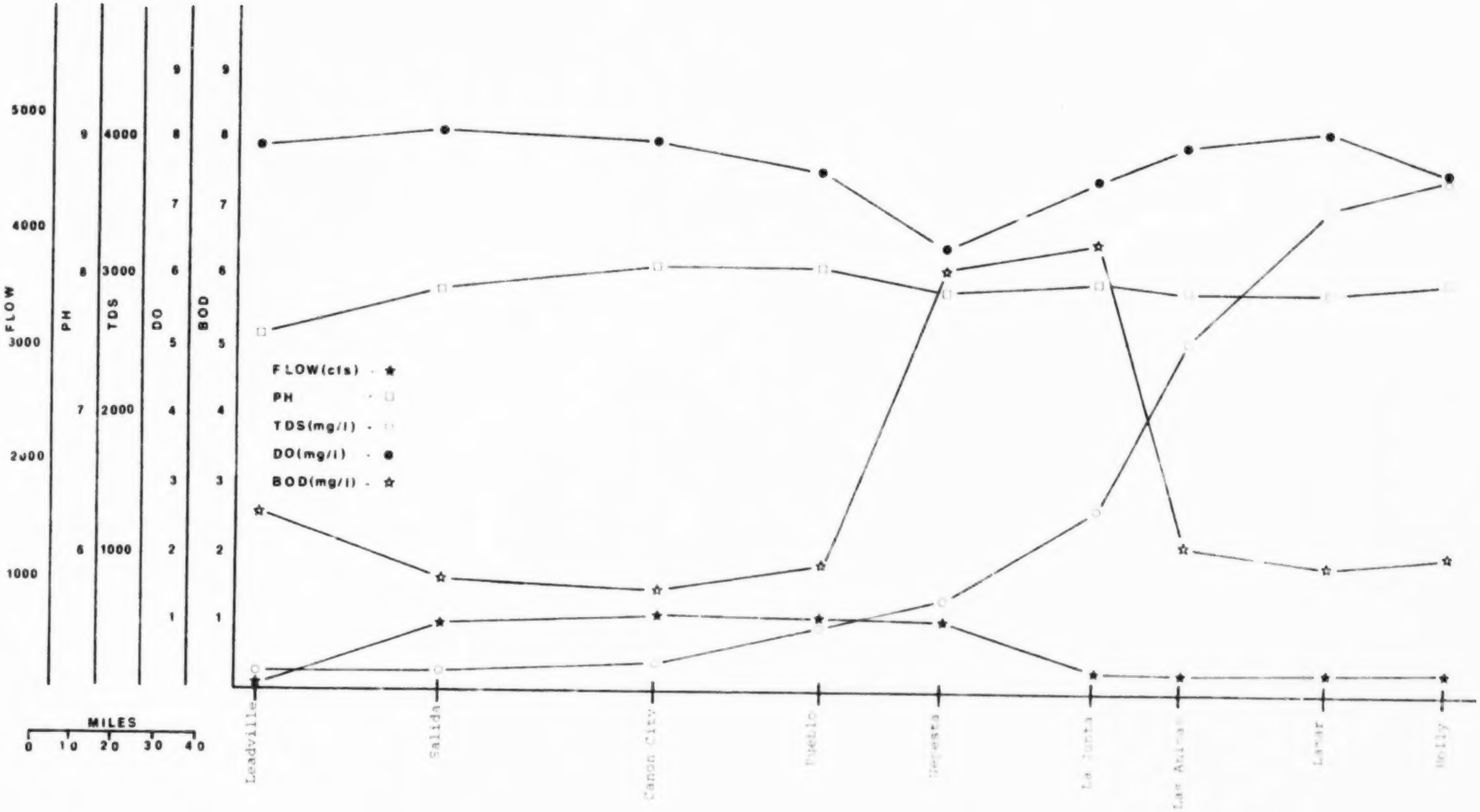

Figure D-1. Arkansas Main Stem Water Quality Characterization with Proposed Sampling Point Locations.

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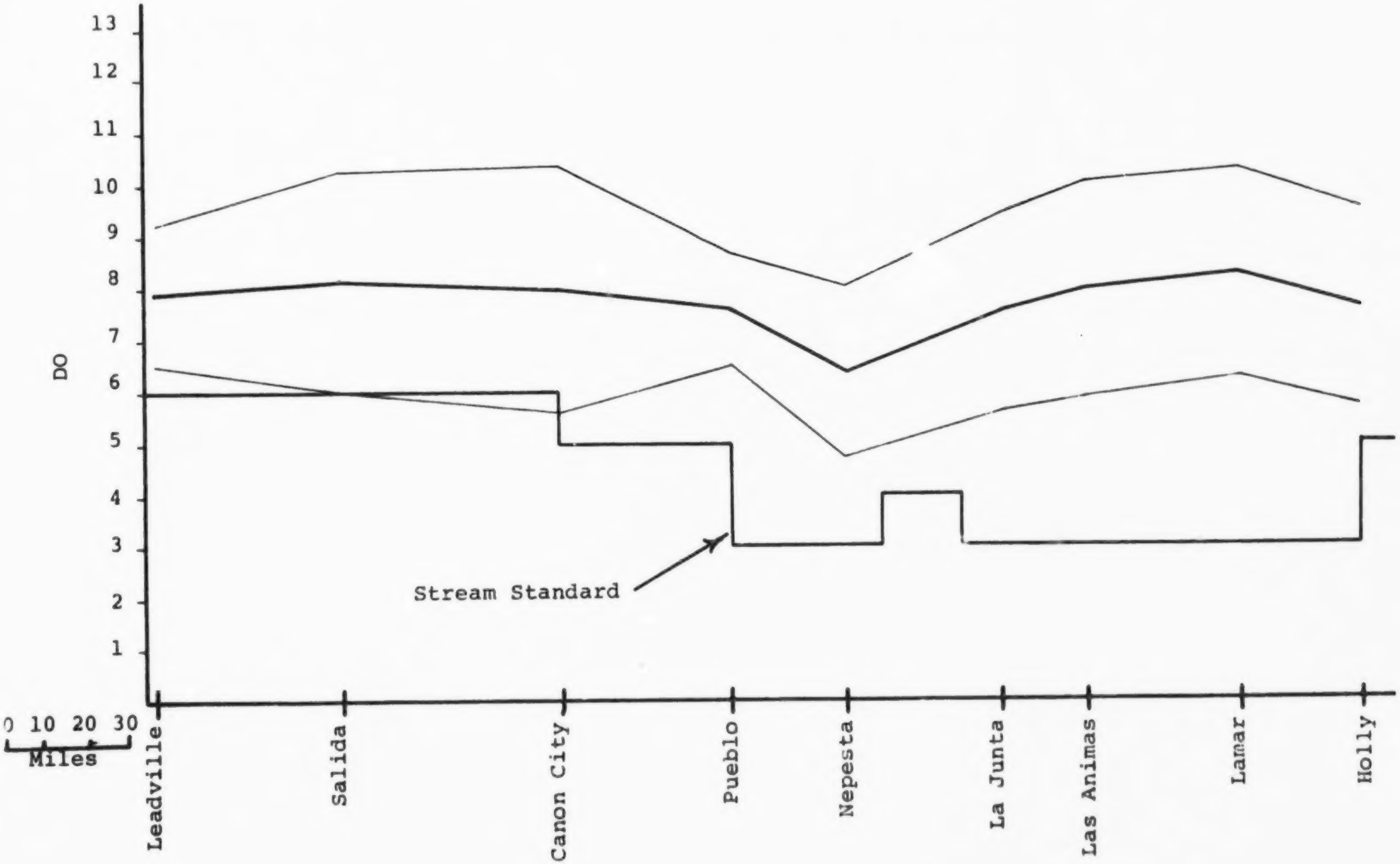

Figure D-2. Mean Dissolved Oxygen for the Arkansas Main Stream with Standard Deviation and Stream Standard Illustrated.

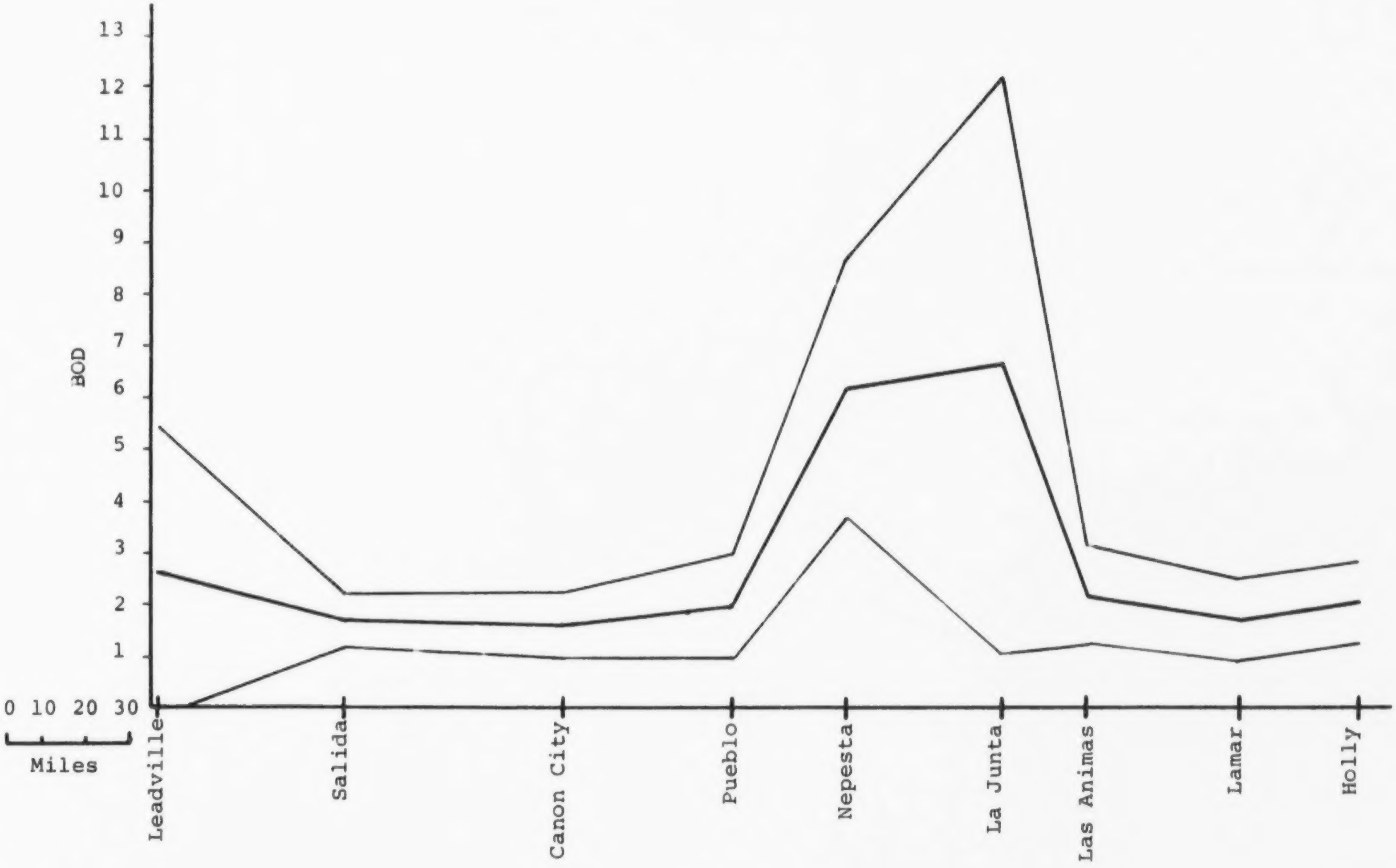

Figure D-3. Mean Biochemical Oxygen Demand for the Arkansas Main Stream with Standard Deviation Illustrated.

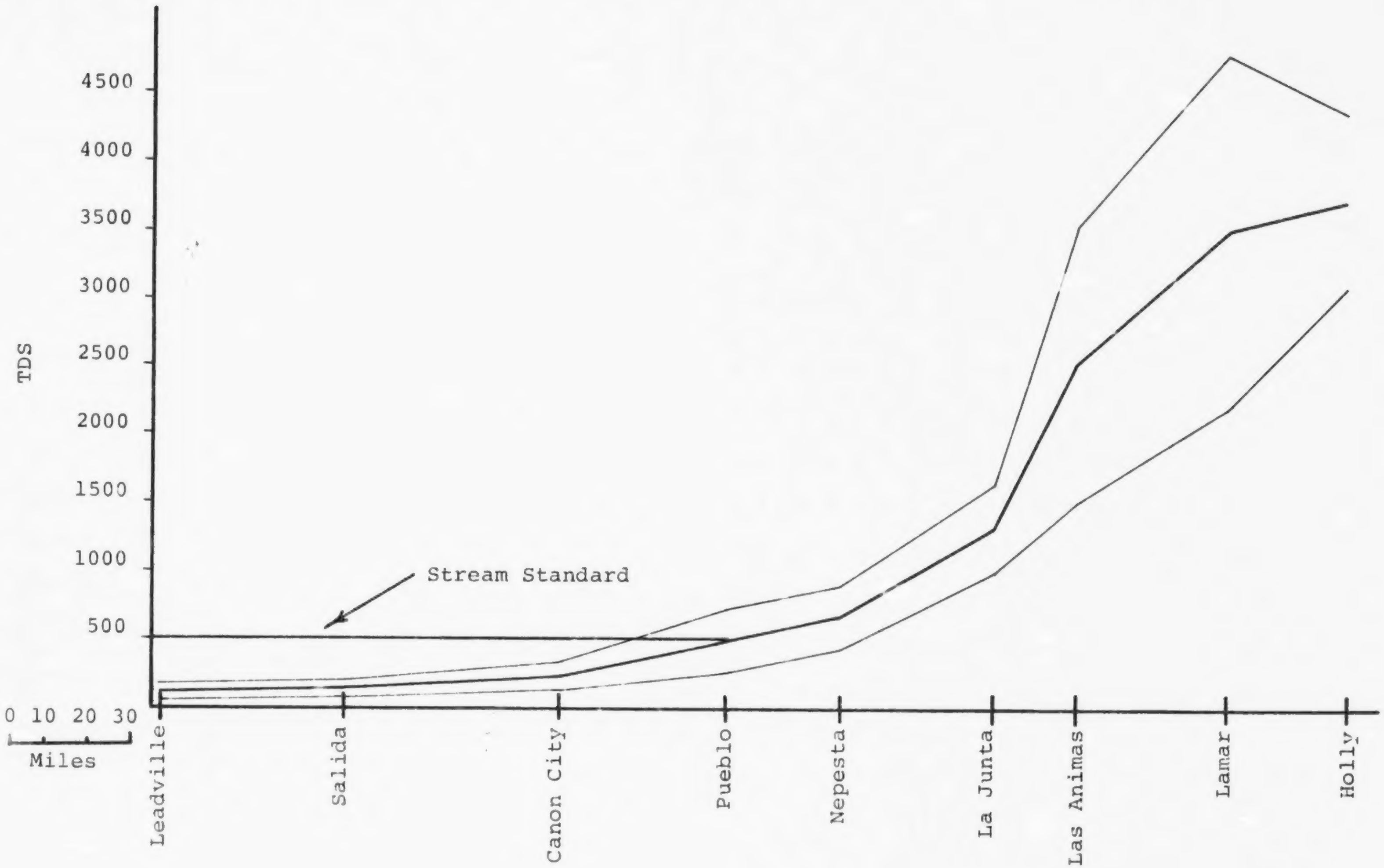

Figure D-4. Mean Total Dissolved Solids for the Arkansas Main Stream with Standard Deviation and Stream Standard Illustrated.

Table D-1. Arkansas Main Stem Stream Characterization Data

Sta No	Location	DO (mg/l)			BOD (mg/l)		pH			TDS (mg/l)			Flow[4] (cfs)
		M[1]	S D[2]	S S[3]	M	S D	M	S D	S S	M	S D	S S	M
1P[5]	Holly	7.5	1.9	5.0	2.0	0.8	8.0	0.5	6.5-8.5	3700	640	Agric	233
2S[6]	Lamar	8.2	2.0	3.0	1.8	0.8	7.9	0.3	5.9-9.0	3500	1300	Agric	224
3S	Las Animas	7.9	2.1	3.0	2.1	1.0	7.9	0.3	5.9-9.0	2500	1000	Agric	214
4P	La Junta	7.4	1.9	3.0	6.5	5.6	8.0	0.4	5.9-9.0	1300	360	Agric	251
5P	Nepesta	6.4	1.7	3.0	6.1	2.4	7.9	0.4	5.9-9.0	650	220	Agric	683
6S	Pueblo	7.6	1.1	5.0	1.8	1.0	8.1	0.4	6.5-8.5	480	220	<500	707
7S	Canon City	8.0	2.4	5.0	1.5	0.7	8.1	0.4	6.5-8.5	180	58	<500	718
8S	Salida	8.1	2.1	6.0	1.6	0.5	7.9	0.4	6.5-8.5	130	34	<500	626
9S	Leadville	7.9	1.3	6.0	2.6	2.8	7.6	0.7	6.5-8.5	120	34	<500	70.8

[1] Mean
[2] Standard Deviation
[3] Stream Standard
[4] USGS Data, Surface Water Records
[5] WPCD Station Number, with P Indicating Primary Station Designation
[6] WPCD Station Number, with S Indicating Secondary Station Designation

Table D-2. Arkansas Tributary Stream Characterization Data.

Sta No	Tributary	Parameter	M	S D	S S
10 S	Purgatoire (near Las Animas)	DO (mg/l)	8.37	2.41	3.0
		BOD "	1.74	0.93	
		pH	8.13	0.33	5.0-9.0
		TDS "	3038.19	957.81	Agric.
		Flow (cfs)	134.00		
11 S	Purgatoire (below Trinidad)	DO	6.85	1.55	3.0
		BOD	1.39	0.52	
		pH	8.17	0.26	5.0-9.0
		TDS	2784.00	863.82	Agric.
		Flow	87.50		
12 S	Apishapa (near Fowler)	DO	7.36	1.95	3.0
		BOD	4.01	2.15	
		pH	7.93	0.32	5.0-9.0
		TDS	1489.64	808.46	Agric.
		Flow	34.30		
13 S	Huerfano (near Boone)	DO	6.84	2.37	3.0
		BOD	3.61	6.67	
		pH	8.13	0.45	5.0-9.0
		TDS	3366.30	1655.36	Agric.
		Flow	-		
14 S	Cucharas (below Walsenburg)	DO	8.04	1.63	3.0
		BOD	2.28	1.24	
		pH	8.41	0.28	5.0-9.0
		TDS	2776.62	1374.49	Agric.
		Flow	-		

Table D-2. (Continued)

Sta No	Tributary	Parameter	M	S D	S S
15S	Fountain Creek (at Pueblo)	DO	7.85	2.23	
		BOD	3.37	3.20	
		pH	8.06	.42	
		TDS	1588.56	427.64	Agric.
		Flow	-		
16P	Fountain Creek (below Colo Sp)	DO	5.21	1.88	
		BOD	29.10	22.23	
		pH	7.85	.39	
		TDS	491.89	304.01	Agric.
		Flow	11.8		
17S	Fountain Creek (near Manitou)	DO	7.71	2.16	6ppm
		BOD	1.44	.63	
		pH	8.03	.45	6.5-8.5
		TDS	126.57	17.57	<500mg/l
		Flow	-		

Colorado River Basin

The Colorado River and its tributaries which originate in the state represent the major undeveloped water supplies in Colorado. The river begins in the Rocky Mountain National Park where peaks are more than 14,000 feet high. The river runs south for a short distance and then flows southwest until it enters Utah at approximately 4,500 feet. The Colorado River drainage area in Colorado is approximately 17,900 square miles and has an estimated average annual yield of 11,150,000 acre-feet. Trans-mountain diversions export large quantities of this water to the South Platte and Arknasas River Basins.

High mineral concentrations are characteristic of Colorado River water as it crosses the mesa and plateau area of western Colorado. These concentrations of dissolved solids, sodium, sulfate, and chloride increase downstream. The mineral concentrations are caused by the geological character of the terrain over which the river flows.

The major tributaries to the Colorado River in Colorado are the Blue River, Eagle River, Roaring Fork River, Gunnison River and Uncompahgre River.

Figures D-5, D-6, D-7, and D-8 are used to graphically characterize water quality of the main stem of the Colorado River. Tables D-3 and D-4 contain the data used in characterizing the Colorado River.

South Platte River Basin

The South Platte River begins in the front ranges of the Rocky Moutains and flows in a northeast direction for 450 miles until it junctions with the North Platte River in Nebraska. Its drainage area consists of 24,030 square miles of which 19,022 are in Colorado. The basin lies within the semi-arid plains region where the average precipitation is from 12 to 14 inches. The snow melt and mountain showers constitute a large part of the flow.

Clear Creek, St. Vrain Creek, Little Thompson River, Big Thompson River, and Cache la Poudre River are the main tributaries. All of these drain mountain regions to the west of the main stem and are perennial. They contribute heavily to the regular flow of the main stem.

Irrigation constitutes the large use of South Platte water. The basin is estimated to be 69 percent farm land, most of which is fertile, irrigated crop land. Currently,

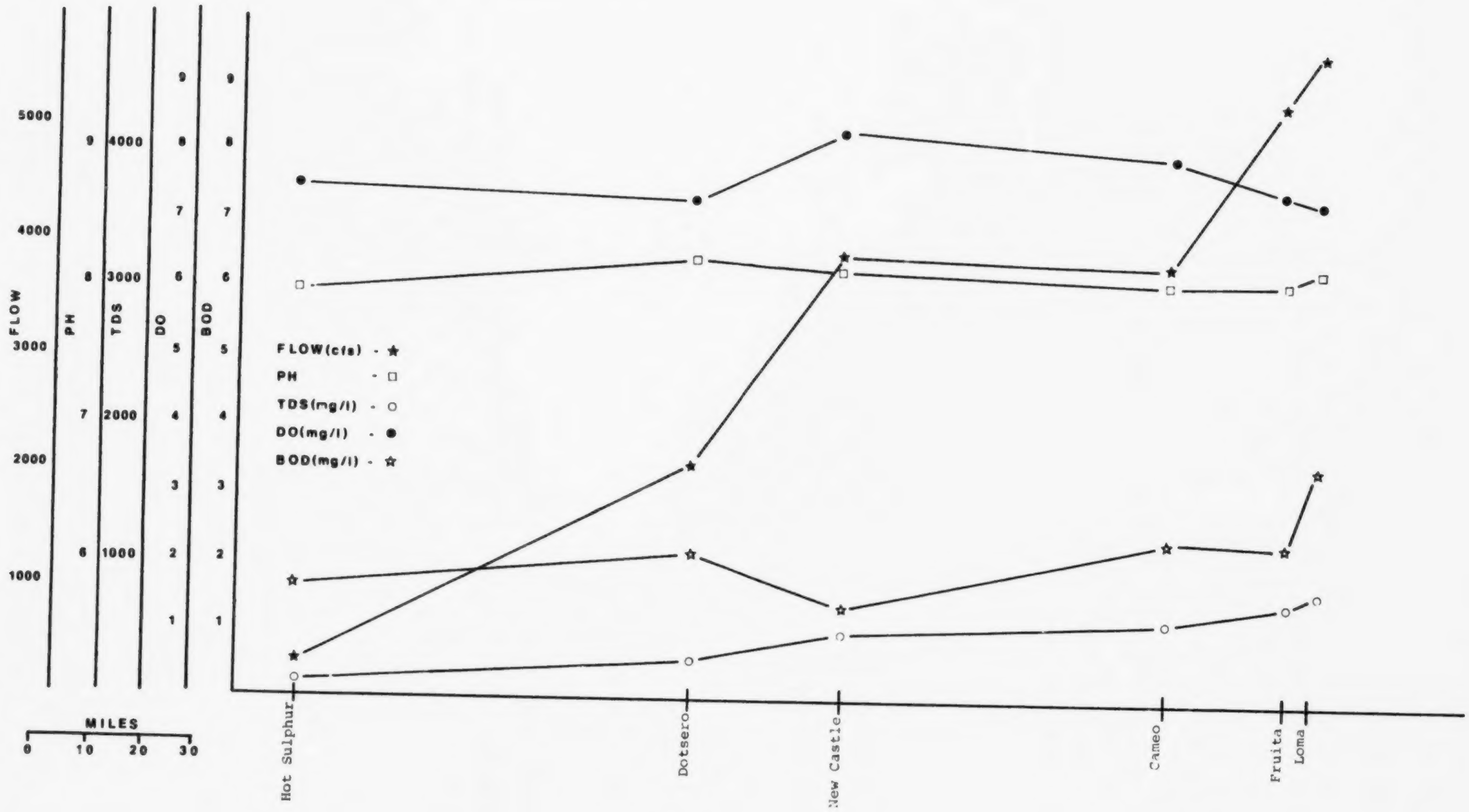

Figure D-5. Colorado Main Stem Water Quality Characterization with Proposed Sampling Point Locations.

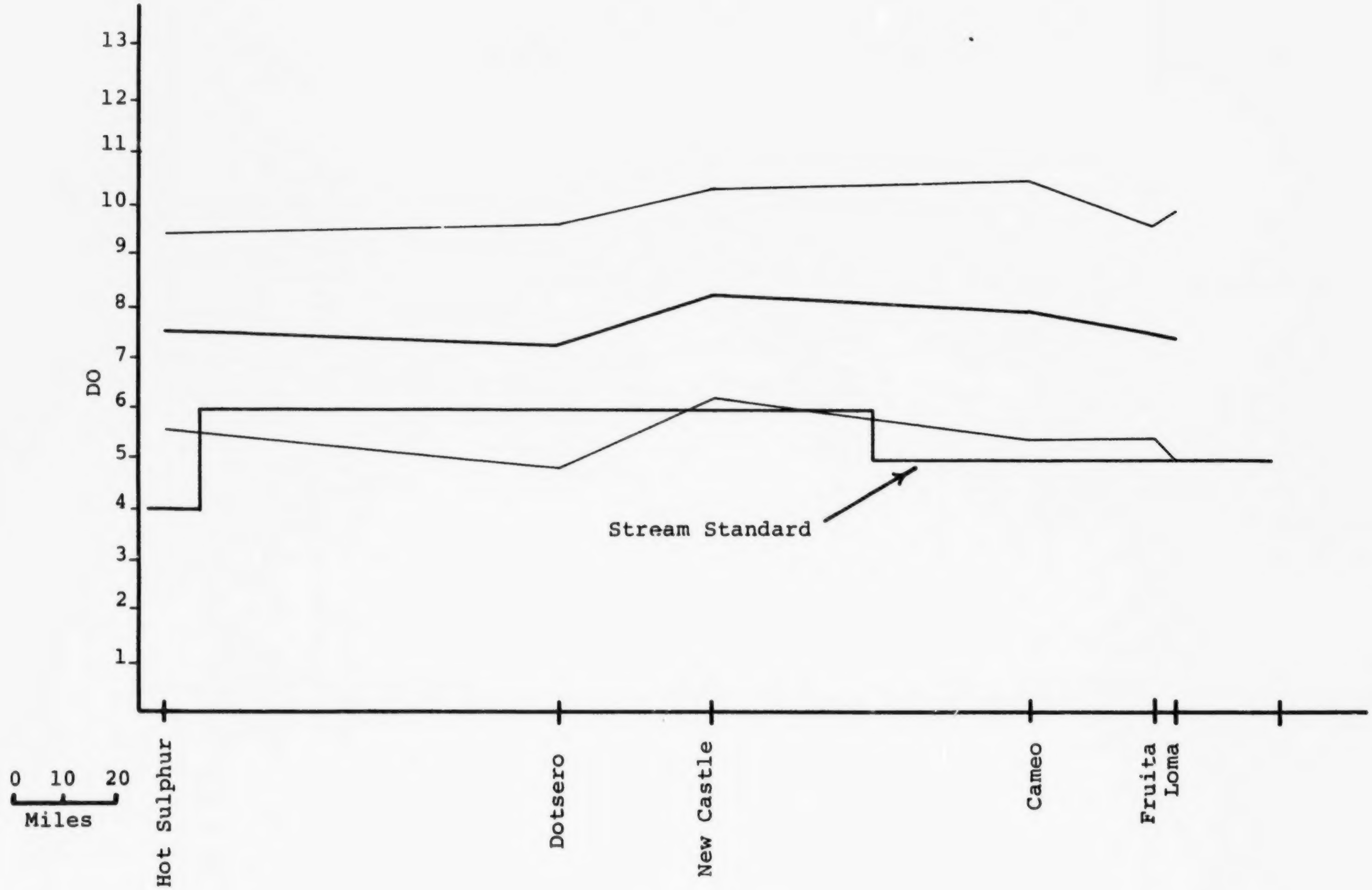

Figure D-6. Mean Dissolved Oxygen for the Colorado Main Stream with Standard Deviation and Stream Standard Illustrated.

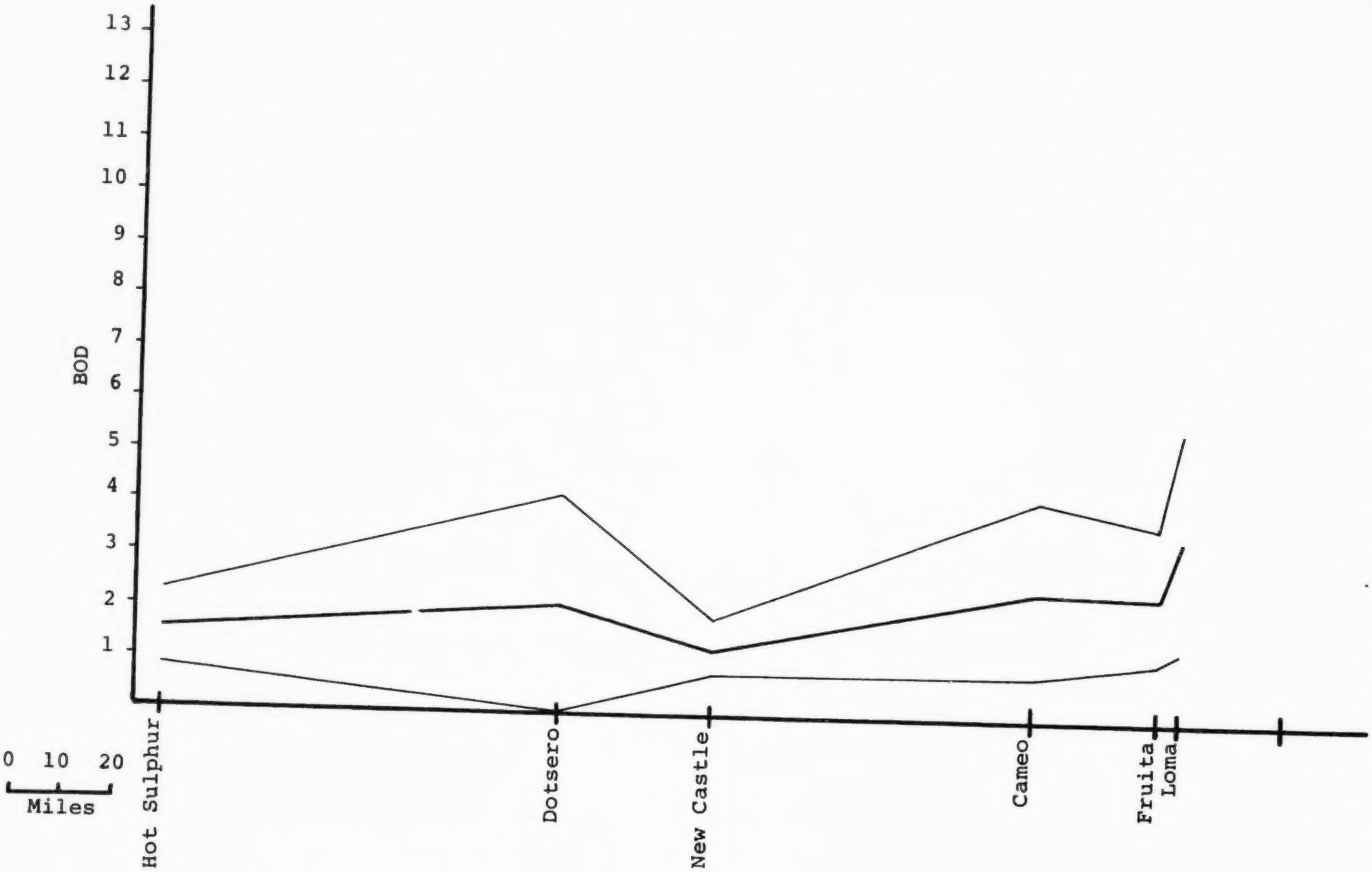

Figure D-7. Mean Biochemical Oxygen Demand for the Colorado Main Stem with Standard Deviation Illustrated.

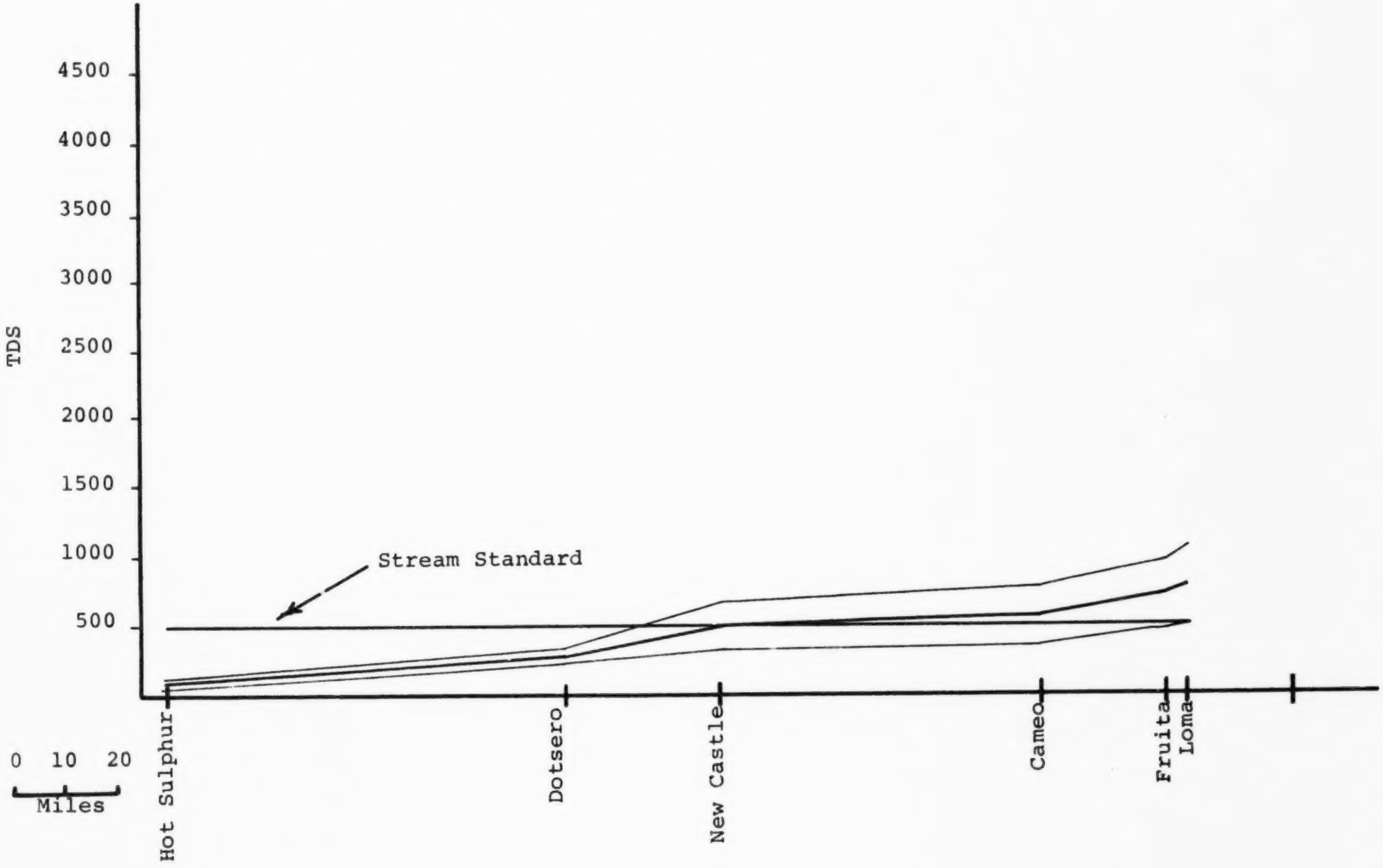

Figure D-8. Mean Total Dissolved Solids for the Colorado Main Stream with Standard Deviation and Stream Standard Illustrated.

Table D-3. Colorado Main Stem Stream Characterization Data.

Sta No	Location	DO (mg/l)			BOD (mg/l)		pH			TDS (mg/l)			Flow (cfs)
		M	S D	S S	M	S D	M	S D	S S	M	S D	S S	M
45S	Hot Sulphur Springs	7.5	1.9	4.0	1.6	0.7	7.9	0.4	6.0-9.0	102	21	500	272
46P	Dotsero	7.2	2.3	6.0	2.1	2.1	8.2	0.6	6.5-8.5	261	57	500	2,082
47S	New Castle	8.2	2.0	6.0	1.3	0.5	8.1	0.5	6.5-8.5	492	158	500	3,888
48S	Cameo	7.9	2.5	5.0	2.4	1.6	8.0	0.4	6.5-8.5	532	205	500	3,831
49S	Fruita	7.4	2.1	5.0	2.3	1.3	8.1	0.4	6.5-8.5	729	241	500	
50P	Loma	7.3	2.4	5.0	3.4	2.1	8.1	0.5	6.5-8.5	773	269	500	5,692

Table D-4. Colorado Tributary Stream Characterization Data.

Sta No	Tributary	Parameter	M	S D	S S
52P	Eagle River (at Gypsum)	DO	7.60	2.25	6 ppm
		BOD	1.31	.56	
		pH	8.09	.53	6.5-8.5
		TDS	501.26	209.14	Agric
		Flow	561		
53P	Roaring Fork (at Mouth)	DO	8.02	2.48	6 ppm
		BOD	1.39	.59	
		pH	8.23	.58	6.5-8.5
		TDS	366.71	95.42	<500 mg/l
		Flow	1,367		
54P	Gunnison (S.E. of G. Junct)	DO	7.95	1.91	5 ppm
		BOD	1.36	.43	
		pH	8.28	.45	6.5-8.5
		TDS	721.41	322.15	<500 mg/l
		Flow	2,558		
55P	Uncompahgre (Tributary to Gunnison River at Delta)	DO	7.78	2.02	4 ppm
		BOD	1.97	.97	
		pH	8.20	.54	6.0-9.0
		TDS	1451.86	496.87	<500 mg/l
		Flow	274		
56S	Gunnison (near Delta)	DO	7.94	1.90	5 ppm
		BOD	1.31	.46	
		pH	8.26	.59	6.5-8.5
		TDS	376.57	186.69	<500 mg/l
		Flow	-		

Table D-4. (Continued)

Sta No	Tributary	Parameter	M	S D	S S
57S	Gunnison (west of Gunnison)	DO	8.60	2.31	6 ppm
		BOD	1.44	.76	
		pH	8.00	.46	6.5-8.5
		TDS	140.79	21.59	<500 mg/l
		Flow	775		
58S	Taylor River (Tributary to Gunnison River at Almont)	DO	8.19	2.01	6 ppm
		BOD	1.20	.97	
		pH	7.95	.47	6.5-8.5
		TDS	86.13	22.73	<500 mg/l
		Flow	338		
59S	Tomichi Creek (Tributary to Gunnison River at Gunnison)	DO	7.67	2.41	6 ppm
		BOD	1.63	.71	
		pH	7.85	.38	6.5-8.5
		TDS	177.75	41.37	<500 mg/l
		Flow	166		
87S	Rock Creek (near McCoy)	DO	9.97	.40	6 ppm
		BOD	2.00		
		pH	7.50	.36	6.5-8.5
		TDS	230.00	14.53	<500 mg/l
		Flow	-		
74S	Gore Creek (at mouth) (Tributary to Eagle River)	DO	7.87	2.28	6 ppm
		BOD	3.17	4.85	
		pH	8.28	.65	6.5-8.5
		TDS	144.16	108.39	Agric
		Flow	-		

Table D-4. (Continued)

Sta No	Tributary	Parameter	M	S D	S S
75S	Gore Creek (Tributary to Eagle River at Bighorn Subdiv)	DO	7.90	2.12	6 ppm
		BOD	1.56	1.46	
		pH	7.88	.46	6.5-8.5
		TDS	61.19	22.63	Agric
		Flow	27.3		
77S	Ten Mile Creek (at Kokomo) (Tributary to Blue River)	DO	9.07	1.80	6 ppm
		BOD	.70	.17	
		pH	7.40	.31	6.5-8.5
		TDS	213.83	172.07	<500 mg/l
		Flow	-		
76S	Eagle River (at Aron Bridge)	DO	8.28	1.63	6 ppm
		BOD	2.66	2.95	
		pH	7.79	.52	6.5-8.5
		TDS	287.60	207.67	Agric
		Flow	-		
83S	Eagle River (near Pando)	DO	8.52	1.42	6 ppm
		BOD	2.84	4.02	
		pH	7.41	.37	615-8.5
		TDS	86.57	40.90	<500 mg/l
		Flow	51.0		
79S	Uncompahgre (at Ridgway) (Tributary to Gunnison River)	DO	7.87	1.65	4 ppm
		BOD	1.06	.40	
		pH	7.91	.40	6.0-9.0
		TDS	448.23	154.03	<500 mg/l
		Flow	155		
78S	East River (Tributary of Taylor River at Confl. with Taylor)	DO	7.89	2.21	6 ppm
		BOD	.97	.85	
		pH	8.01	.46	6.5-8.5
		TDS	174.95	24.77	<500 mg/l
		Flow	341		

municipal and industrial water needs are competing with agriculture for the water and the competition grows as the urbanization of the basin continues at a very rapid rate.

Figures D-9, D-10, D-11, and D-12 graphically describe the water quality of the South Platte main stem. Figure D-9 is a composite, while Figures D-10, D-11, and D-12 illustrate variations in the river. Tables D-5 and D-6 give the water quality data for the main stem and tributaries, respectively.

Other River Basins

The three river basins discussed so far are the major streams with respect to flow and population. The rivers mentioned here are sizeable, but they do not have large drainage basins or high concentrations of human activity.

The Dolores River is located in the southwestern part of Colorado and is a tributary to the Colorado River junctioning with the main stem outside of Colorado. The Dolores River drainage area contains little population. Stream characterization data for the Dolores River is in Table D-7.

The Green Yampa Basin is in northwestern Colorado and these waters also reach the Colorado River outside the state. The Green River just barely dips into Colorado as it makes its way down from the north. The Yampa River drainage area lies almost completely in Colorado and in junctions with the Green, while the Green River is in Colorado. Table D-8 contains the available water quality data for the Green-Yampa Basin.

The North Platte River rises in the north central portion of Colorado and flows into Wyoming. The river drains he North Park area of Colorado where there is little population. Table D-9 contains the existing water quality characterization data for the North Platte River.

The Republican River Basin is located on the high plains in the eastern central part of Colorado. Bonny Reservoir regulates the flow of the river which has had an average discharge of 24.8 cfs since 1951. The Republican River joins the Kansas River in Kansas. Table D-10 contains the characterization data for this river.

The headwaters of the Rio Grande River are located in the south central part of Colorado and the flow yields 380,000 acre-feet or about 8 percent of the total for the state. The drainage area of the river consists of the San Luis

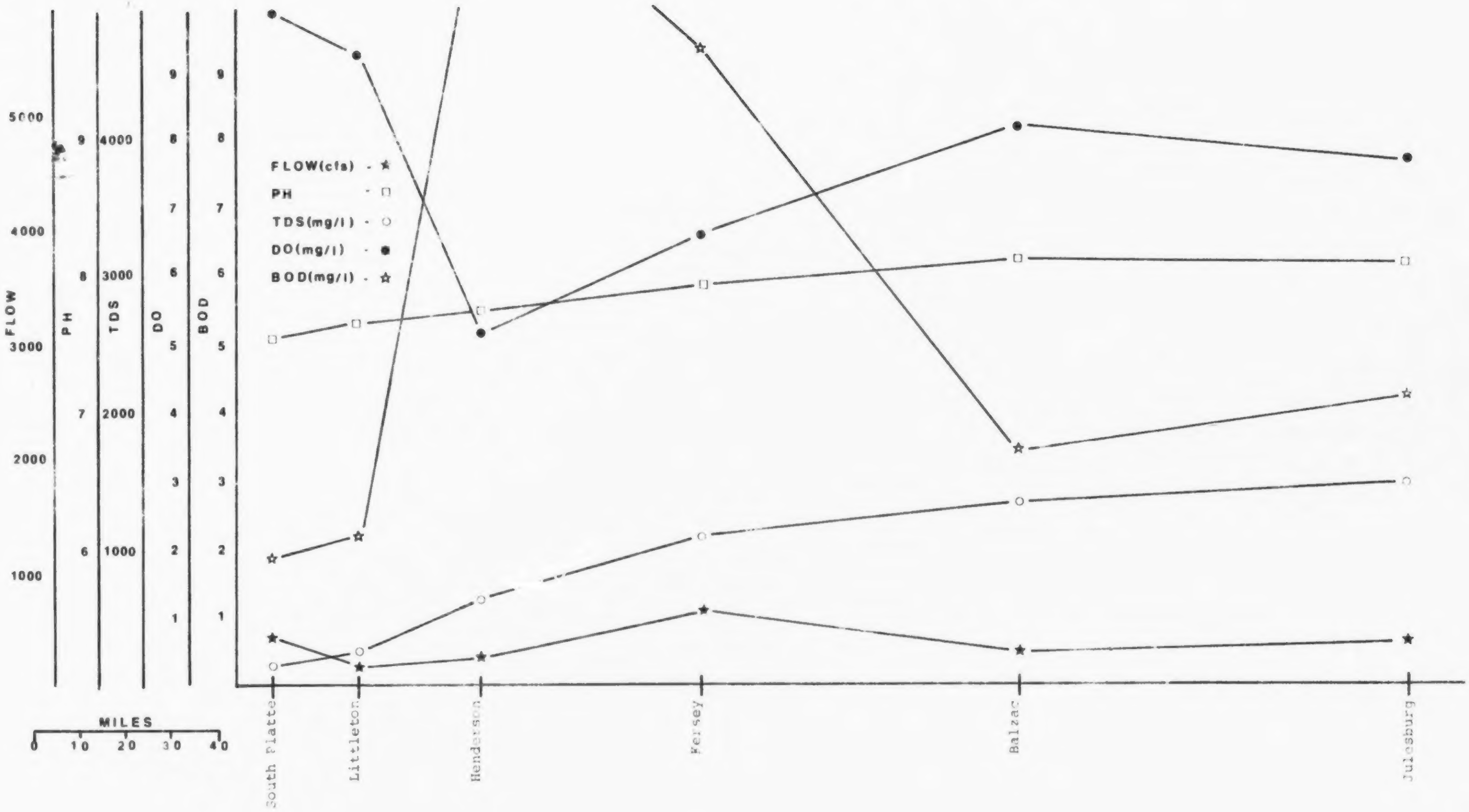

Figure D-9. South Platte Main Stem Water Quality Characterization with Proposed Sampling Point Locations.

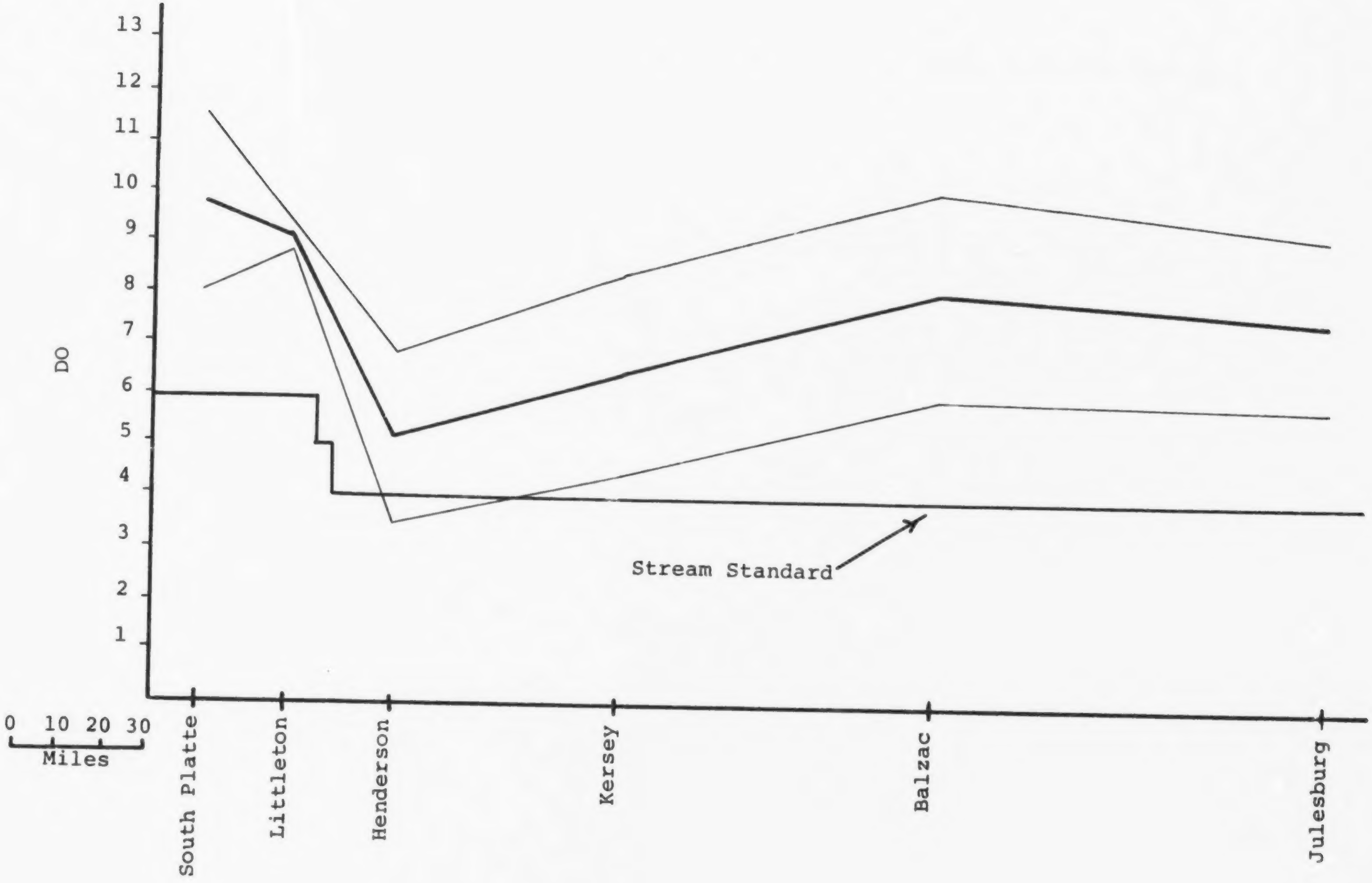

Figure D-10. Mean Dissolved Oxygen for the South Platte Main Stream with Standard Deviation and Stream Standard Illustrated.

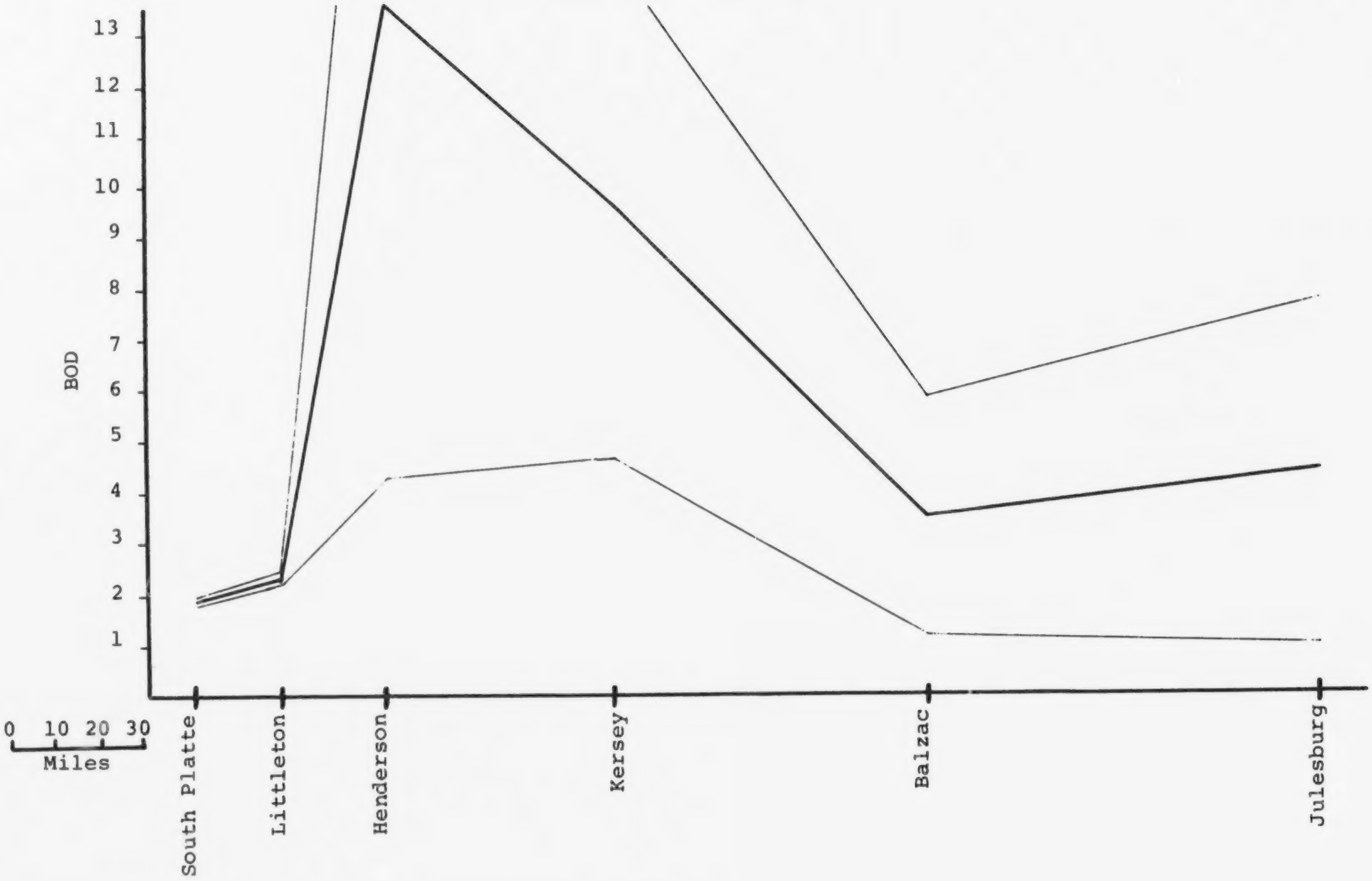

Figure D-11. Mean Biochemical Oxygen Demand for the South Platte Main Stream with Standard Deviation Illustrated.

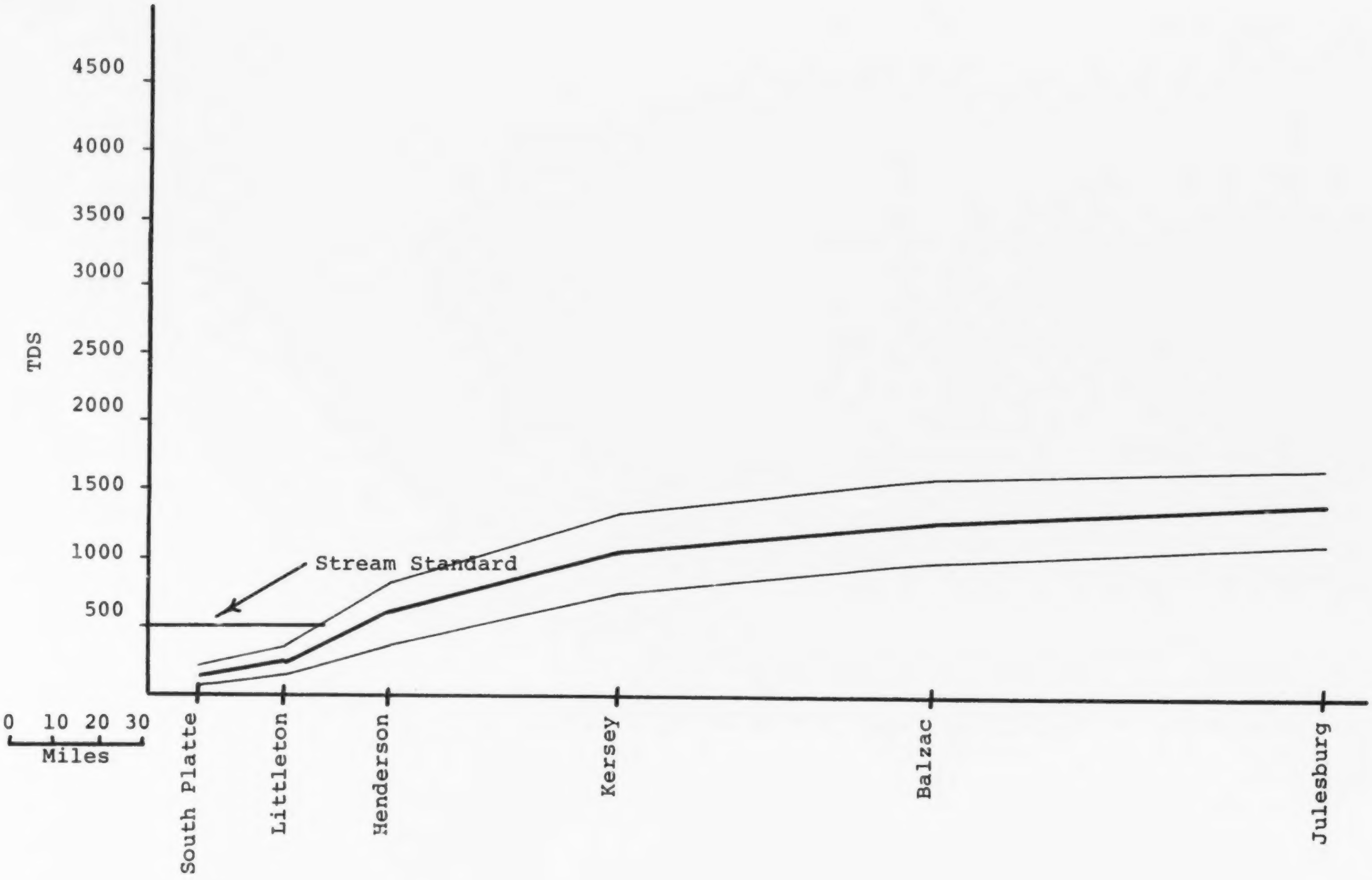

Figure D-12. Mean Total Dissolved Solids for the South Platte Main Stream with Standard Deviation and Stream Standard Illustrated.

Table D-5. South Platte Main Stem Stream Characterization Data.

Sta No	Location	DO (mg/l)			BOD (mg/l)		pH			TDS (mg/l)			Flow (cfs)
		M	S D	S S	M	S D	M	S D	S S	M	S D	S S	M
20	Julesburg	7.7	1.7	4.0	4.2	3.4	8.1	0.4	6.0-9.0	1438	282	<500	458
21	Balzac	8.2	2.0	4.0	3.5	2.3	8.1	0.5	6.0-9.0	1287	296	<500	359
22	Kersey	6.6	1.8	4.0	9.6	4.9	7.9	0.4	6.0-9.0	1045	290	<500	130
23	Henderson	5.2	1.6	4.0	13.8	9.4	7.7	0.4	6.0-9.0	584	221	<500	328
24	Littleton	9.2	0.3	6.0	2.2	0.7	7.7	0.2	6.5-8.5	218	54	<500	217
25	South Platte	9.8	1.7	6.0	1.9	0.2	7.6	0.2	6.5-8.5	126	47	<500	474

Table D-6. South Platte Tributary Stream Characterization Data.

Sta No	Tributary	Parameter	M	S D	S S
26S	Cacha La Poudre (above Ft. Collins)	DO	7.72	1.84	6 ppm
		BOD	1.78	.99	
		pH	8.29	.54	6.5-8.5
		TDS	69.31	34.10	<500 mg/l
		Flow	282		
27P	Cacha La Poudre (near Greeley)	DO	6.22	1.73	3
		BOD	26.99	22.38	
		pH	7.93	.47	5.0-9.0
		TDS	1421.26	192.24	Agric
		Flow	96.0		
28P	Big Thompson (near Mouth)	DO	6.38	2.43	4 ppm
		BOD	17.21	21.18	
		pH	8.00	.46	6.0-9.0
		TDS	1673.89	451.18	<500 mg/l
		Flow	71.9		
29S	St. Vrain (near Mouth)	DO	6.44	1.45	4 ppm
		BOD	5.88	3.26	
		pH	7.94	.38	6.0-9.0
		TDS	936.45	337.48	<500 mg/l
		Flow	196		
30S	St. Vrain (at Weld-Boulder County Line)	DO	4.00	1.46	4 ppm
		BOD	14.27	5.79	
		pH	8.1	0.32	6.0-9.0
		TDS	864.71	138.27	<500 mg/l
		Flow	-		

Table D-6. (Continued)

Sta No	Tributary	Parameter	M	S D	S S
31P	St. Vrain (below Longmont)	DO	6.62	1.17	4 ppm
		BOD	11.51	4.79	
		pH	8.28	.55	6.0-9.0
		TDS	673.54	414.49	<500 mg/l
		Flow	-		
32S	Left Hand Creek (near Niwot) (Tributary to St. Vrain River)	DO	7.80	-	4 ppm
		BOD	1.57	.40	
		pH	7.90	-	6.0-9.0
		TDS	632.00	-	<500 mg/l
		Flow	-		
33P	Boulder Creek (at Boulder-Weld County Line) (Tributary to St. Vrain River)	DO	7.91	2.30	5 ppm
		BOD	7.38	2.79	
		pH	8.23	.53	6.5-8.5
		TDS	358.07	180.39	<500 mg/l
		Flow	90.6 (Boulder)		
34P	Clear Creek (near Mouth)	DO	7.60	2.05	4 ppm
		BOD	9.93	3.89	
		pH	7.99	.45	6.0-9.0
		TDS	412.83	179.46	<500 mg/l
		Flow	90.9		
89P	Clear Creek (at Wheat Ridge)	DO	8.95	-	4 ppm
		BOD	15.00	-	
		pH	7.45	-	6.0-9.0
		TDS	243.00	-	<500 mg/l
		Flow	-		

Table D-6. (Continued)

Sta No	Tributary	Parameter	M	S D	S S
35P	Clear Creek (above Golden)	DO	6.71	3.85	6 ppm
		BOD	2.40	1.01	
		pH	7.49	.34	6.5-8.5
		TDS	160.95	70.64	<500 mg/l
		Flow	227		
36P	Bear Creek (at Jeff.-Arap. County Line)	DO	7.52	3.04	5 ppm
		BOD	2.15	.65	
		pH	7.82	.32	6.5-8.5
		TDS	203.67	119.27	Agric
		Flow	34.9		

Table D-7. Dolores River Stream Characterization Data.

Sta No	Tributary	Parameter	M	S D	S S
84S	San Miguel (at Confl. with Dolores) (Tributary to Dolores)	DO	7.18	1.80	4 ppm
		BOD	5.44	1.47	
		pH	7.94	.33	6.0-9.0
		TDS	655.40	295.26	<500 mg/l
		Flow	339 (Naturita)		
61S	Dolores (at Gateway)	DO	7.83	2.02	5 ppm
		BOD	8.57	13.59	
		pH	7.97	.38	6.5-8.5
		TDS	1759.96	1092.74	<500 mg/l
		Flow	-		
85S	Dolores (at Bedrock)	DO	7.10	1.45	5 ppm
		BOD	.45	.21	
		pH	7.94	.27	6.5-8.5
		TDS	3328.83	2705.83	<500 mg/l
		Flow	-		
80S	Dolores (near Dolores)	DO	7.85	1.77	6 ppm
		BOD	.92	.59	
		pH	8.04	.56	6.5-8.5
		TDS	229.23	67.23	<500 mg/l
		Flow	430		

Table D-8. Green-Yampa Rivers Stream Characterization Data.

Sta No	Tributary	Parameter	M	S D	S S
88S	Yampa (above Oak Creek Confl.)	DO	7.87	.61	6 ppm
		BOD	3.50	2.26	
		pH	7.70	.73	6.5-8.5
		TDS	234.67	39.72	<500 mg/l
		Flow	81.7		
38S	Yampa (at Milner)	DO	7.66	1.78	6 ppm
		BOD	1.82	1.25	
		pH	7.96	.49	6.5-8.5
		TDS	148.96	68.79	<500 mg/l
		Flow	-		
39S	Yampa (near Maybell)	DO	7.36	1.92	5 ppm
		BOD	2.00	1.71	
		pH	7.72	1.45	6.5-8.5
		TDS	286.00	115.46	Agric
		Flow	1537		
40S	Yampa (below Little Snake River)	DO	7.47	1.69	5 ppm
		BOD	2.04	1.35	
		pH	8.15	.43	6.5-8.5
		TDS	295.08	113.59	Agric
		Flow	-		
41S	Little Snake (above Lily) (Tributary to Yampa River)	DO	7.51	1.52	
		BOD	2.04	1.79	
		pH	8.15	.42	
		TDS	359.71	177.00	Agric
		Flow	560		

Table D-9. North Platte River Stream Characterization Data.

Sta No	Tributary	Parameter	M	S D	S S
37S	North Platte (below Cowdrey)	DO	6.82	1.53	6 ppm
		BOD	1.17	.73	
		pH	7.89	.39	6.5-8.5
		TDS	190.52	45.29	<500 mg/l
		Flow	429		

Table D-10. Republican River Stream Characterization Data.

Sta No	Tributary	Parameter	M	S D	S S
70S	Republican (below Bonny Res.)	DO	7.69	2.20	5 ppm
		BOD	2.11	.78	
		pH	8.29	.49	6.5-8.5
		TDS	317.84	34.93	Agric
		Flow	24.8		

Valley, which is 7.9 percent of the land area of Colorado. The valley, however, only contains 2 percent of Colorado's total population. Nearly 52 percent of the area is federal land serving as National Forests and Monuments. Agriculture dominates the economy and is the major user of the Rio Grande water. Table D-11 contains the characterization data for the Rio Grande River.

The San Juan River is located in the southwestern part of the state and its tributaries drain the southern part of the San Juan Mountains. The San Juan leaves Colorado early in its journey to the Colorado River, and consequently, its tributaries must cross state boundaries. The San Juan barely cuts the Colorado corner of the "Four Corners" area before it leaves Colorado for good. Characterization data in contained in Table D-12.

The White River is located in the west central area of Colorado, and it meets the Green River in Utah. The population in the White Basin is very small, but the oil shale deposits might create problems as they are mined in this and other areas of Colorado. Characterization data for the White River is seen in Table D-13.

Table D-11. Rio Grande River Basin Stream Characterization Data.

Sta No	Tributary	Parameter	M	S D	S S
18S	Rio Grande (East of Manassa)	DO	7.53	1.86	6 ppm
		BOD	1.66	.46	
		pH	7.92	.41	6.5-8.5
		TDS	250.41	102.87	Agric
		Flow	603		
19S	Rio Grande (at Alamosa)	DO	7.25	1.77	6 ppm
		BOD	2.20	2.37	
		pH	7.83	.13	6.5-8.5
		TDS	148.72	37.42	Agric
		Flow	254		

Table D-12. San Juan River Stream Characterization Data.

Sta No	Tributary	Parameter	M	S D	S S
63S	San Juan River (near State Line)	DO	7.61	2.39	5 ppm
		BOD	2.00	.97	
		pH	8.07	0.42	6.5-8.5
		TDS	465.14	157.63	-
		Flow	-		
62S	McElmo Creek (west of Cortez)	DO	7.31	1.74	
		BOD	2.84	1.57	
		pH	8.14	.32	
		TDS	2982.04	1036.85	
		Flow	43.1		
64S	Mancos River (3 mi. north of State Line)	DO	7.78	2.04	
		BOD	1.49	.85	
		pH	8.19	.44	
		TDS	1550.65	548.42	
		Flow	50.7		
65S	La Plata River (north of La Plata)	DO	7.81	2.20	6 ppm
		BOD	1.53	.74	
		pH	8.07	.41	6.5-8.5
		TDS	1594.61	1108.73	-
		Flow	45.3		
66S	Animas River (near Bondad)	DO	8.25	2.03	6 ppm
		BOD	1.48	.70	
		pH	8.22	.46	6.5-8.5
		TDS	326.09	103.09	<500 mg/l
		Flow	878		

Table D-12. (Continued)

Sta No	Tributary	Parameter	M	S D	S S
81S	Animas River (above Durango)	DO	8.30	1.86	6 ppm
		BOD	1.83	3.46	
		pH	7.76	.58	6.5-8.5
		TDS	184.08	63.31	<500 mg/1
		Flow	846		
82S	Animas River (near Silverton)	DO	6.66	1.50	3 ppm
		BOD	.27	.06	
		pH	7.71	0.40	5.0-9.0
		TDS	288.80	146.18	-
		Flow	104		
67S	Los Pinos (near La Boca)	DO	8.01	2.05	6 ppm
		BOD	1.78	.75	
		pH	8.29	.44	6.5-8.5
		TDS	152.83	44.90	<500 mg/1
		Flow	190		
68S	San Juan (above Navajo Res.)	DO	8.17	1.86	6 ppm
		BOD	1.66	.99	
		pH	8.03	.35	6.5-8.5
		TDS	215.17	76.26	<500 mg/1
		Flow	636		
69S	Piedra River (N.E. of Arboles County)	DO	8.39	1.80	6 ppm
		BOD	1.67	.77	
		pH	7.80	1.13	6.5-8.5
		TDS	223.79	87.80	-
		Flow	327		

Table D-13. White River Stream Characterization Data.

Sta No	Tributary	Parameter	M	S D	S S
43S	White River (at Meeker)	DO	8.92	[illegible]	5 ppm
		BOD	1.66	.93	
		pH	8.28	.54	6.5-8.5
		TDS	353.20	99.32	<500 mg/l
		Flow	621		
44S	White River (at Rangely)	DO	7.64	1.89	5 ppm
		BOD	1 [illegible]	.73	
		pH	8.25	.45	6.5-8.5
		TDS	466.60	145.67	Agric
		Flow	-		

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